The illustration shows a Hollow Forging under a 2700 tons Press.

STEEL
FORGINGS

HADFIELDS
SHEFFIELD

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More Steel?

ACCORDING to the fifth issue of the Economic Commission for Europe's " Quarterly Bulletin of Steel Statistics," which was published recently, new records have been achieved in European steel production during 1951, the estimated total of 66·7 million tons being 11·5 million tons in excess of the total 1950 production. Apart from Spain, whose output is, in any case, very small, the United Kingdom is the only country producing at a lower rate than in 1950. The final figures for 1951 are now available, and show a fall in steel output from 16,292,700 tons in 1950, to 15,638,500 tons in 1951. Pig-iron production, on the other hand increased from 9,632,900 tons to 9,668,800 tons.

The main reason for this reduction in output is, undoubtedly, the shortage of scrap. Imports at 550,000 tons were very near to the estimated figure, although an indication of the extent to which these imports have fallen may be obtained from the fact that the figures for 1950 approached 2 million tons. Had scrap imports remained at the same level, crude steel production would have reached a new record of some 17·25 million tons, as compared with the 15·6 million tons actually produced. At home, too, the scrap seems to have gone into hiding, and the figures for scrap purchased (3,860,000 tons) are less than had been expected—less, indeed, than those for the previous year. The scrap drive in the steelworks themselves yielded rather more than had been thought likely, but the results from the rest of industry, with no increase at all over 1950, are extremely disappointing.

Important as is the need for more scrap, an increase in steel production in 1952 will depend mainly on an increase in pig-iron production, which, in turn, will depend on the availability of adequate supplies of ore and coke. To produce the required extra million tons of pig-iron will need something like 2 million tons more imported ore. To date, the total contracted for is equivalent to an increase of a million tons over last year, and it will be impossible to obtain the further million tons unless the U.S. steel industry agrees to reduce its purchases of iron ore from Europe and North Africa. At the time time of writing it is believed that, as a result of Mr. Churchill's visit to America, an announcement will shortly be made of details of an Anglo-American agreement providing Britain with American steel and the United States with tin and aluminium. A figure of 1 million tons of steel has been mentioned, but it is not yet known whether it will be in the form of direct steel imports, or whether it will include equivalent supplies of pig-iron and scrap. Nor is it certain whether any arrangement has been reached which will enable Britain to obtain the extra ore needed for an expanded pig-iron production.

Failure to reach the pig-iron production target in 1951 was not due to the shortage of iron ore so much as to the shortage of coke. As increased blast furnace capacity became available the coke position became increasingly serious until, at present, the industry is in need of some further 6,000 tons a week. Our home ores are mainly of relatively low iron content, the mining of ore with an iron content above 42% having fallen from 1,120,000 tons in 1936 to 453,000 tons in 1950, whilst the corresponding figures for ore with less than 42% iron are 11,777,000 and 12,690,000. Coke consumption is higher when smelting these lower grade ores and, although beneficiation is possible on certain types, there are others in which the gangue material cannot readily be separated from the ore by physical means. In consequence, large amounts of flux have to be charged into the blast furnace and a considerable amount of heat is lost in the molten slag tapped off at the hearth.

In a paper* presented recently to the Midland Section of the Coke Oven Managers Association, the importance of good coke quality and the effect it has on blast furnace output is emphasized. Although coke quality is largely dependent on the quality of the slack from which it is made, there are other factors which need to be taken into account. Experience at the Appleby-Frodingham works of The United Steel Companies has shown that differences in coke consumption as high as 3 cwt. per ton of iron made have been obtained using cokes which, judged by the slacks from which they were made, and the batteries in which they were carbonised, should have been of similar, if not identical, quality. It is evident, therefore, that significant economies in coke consumption, or—what is more important at the moment—a substantially improved output of pig-iron. could be made by the up-grading of coke quality.

It is felt within the industry that the failure to achieve a production of 16 million tons of steel in 1951 is due, in large measure, to faulty control by the Ministry of Supply after nationalisation. While steelworks went short of pig-iron and scrap, and, to some extent, of coke, iron foundries were receiving more than the year before, and the output of iron castings exceeded by some 250,000 tons the figure of 3,500,000 tons on which steel output estimates had been based. Furthermore, the continued control of steel sheet—although no longer scarcer than other steel products—and the freedom from restriction of cast iron, had tended to encourage the design of equipment to make more use of castings, such changes generally involving a greater weight of metal. This muddle is attributed to the nationalisation of a limited number of steel concerns, which left the iron foundries and many mixed firms outside control : what is badly needed is the return of the Iron and Steel Board which, prior to nationalisation, successfully supervised the whole field.

* " The Quality of Blast Furnace Coke," by F. J. Hewitt, H. L. Riley and F. Savage. Preprinted from *The Gas World*.

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Wolverhampton Corrugated Iron Co., Ltd.

IN 1922, the Wolverhampton Corrugated Iron Co., Ltd., entered into agreements with the H. H. Robertson Company of Pittsburgh, U.S.A., under which they erected a new factory for the manufacture of Robertson Protected Metal sheeting in their Mersey Iron Works, Ellesmere Port. At first operated as a department of the Sheet Works, the business has developed steadily over the past thirty years, during which the H. H. Robertson Company have built up a separate organisation of world-wide repute handling their patented products.

The H. H. Robertson Company have now purchased the factory in which R.P.M. sheeting, Robertson ventilators and ancillary products are made, together with certain additional land and buildings for expansion. Since January 1st, 1952, therefore, the Robertson Company has been operating independently from the Wolverhampton Corrugated Iron Co., Ltd., under the title of " Robertson Building Service—H. H. Robertson Company."

Direction and management of the Robertson Building Service are unchanged, and employees in the R.P.M. Factory will continue in the service of the H. H. Robertson Company. Wolverhampton Corrugated Iron Company continue in occupation of the remainder of the Mersey Iron Works, where their other products are made.

Selling Agents for Rhodesian Copper
British Metal Corporation appointed

RHOKANA Corporation Ltd. and Nchanga Consolidated Copper Mines Ltd. announce that they have appointed The British Metal Corporation Ltd., of 93, Gresham Street, London, E.C.2., as their agents for the sale of copper throughout the world with the exception of Belgium, France, Switzerland, Northern Rhodesia, Southern Rhodesia and the Union of South Africa.

The Cladding of Metals

By R. D. Weber

Following a brief discussion of the principles of metal cladding, an outline is given of the methods and processes used, particular attention being paid to the techniques of solid-phase bonding. Reference is also made to liquid-phase cladding, by means of continuous casting, and to scrap recovery of clad metals.

OF recent years, the demand for metals having properties unobtainable by conventional means, has greatly increased. This, together with economic considerations, has led to considerable advances being made in the cladding of metals. The inherently different metallurgical characteristics of the two metals is one of the greatest difficulties which have been encountered, and considerable skill and ingenuity have had to be exercised to ensure perfect bonding and workability of the clad metals.

Principles of Cladding

Many theories have been put forward to explain the cladding of metals, and brief reference is made to these below.

The forces for bonding between two solid metals, similar or dissimilar, are the same as the forces responsible for cohesion existing between the atoms in a single piece of metal.

These forces are components of the electromagnetic field of force surrounding metal atoms. At distances of 10 to 20 atomic diameters this field of force is only slightly attractive. As two atoms approach one another the force of attraction increases to a maximum at a critical atomic distance and finally changes into repulsion on closer approach. On an atomic scale even the smoothest ground finish on a metal surface is so rough that two such metal surfaces brought together come into actual contact at only a very few points. Such a system is at equilibrium when the repulsive forces which are set up at the points of contact are equal to the attractive forces between the surfaces not yet in contact. When two metal surfaces are placed together under pressure only a few contact areas of repulsion are available to withstand the applied load and consequently these few points are under enormous pressure. If the pressure is increased until plastic deformation takes place there will be an increase in size and number of the contact areas of repulsion. When the load is released the repulsive forces operate until the equilibrium distance is attained, thus resulting in cladding.

The temperature at which cladding takes place under optimum conditions is very important for the following reasons. The compressive strength of a metal falls rapidly with increasing temperature and, secondly, with high bonding temperatures atomic mobility is increased as well as the rate of diffusion of contaminants away from the cladding line. The cladding temperature should also be chosen with regard to any recrystallisation or phase changes which can take place and affect the diffusion rate of the two metals.

The above considerations apply to the cladding mechanism of ideal metal surfaces. In practice, however, metals always have their surfaces contaminated by liquids, solids, or combinations of them, which interferes, to some extent, with metal to metal contact. These surface layers should be removed before cladding. Chemical and mechanical cleaning, such as degreasing, pickling and grinding, can reduce these layers to a minimum but can never remove them completely.

Kinzel showed that metal oxides such as Fe_2O_3 can readily diffuse away from the cladding line into the parent metal, the rate of diffusion being a function of time and temperature. Durst noticed that CuO also diffuses away from the cladding line and assumed that the speed of diffusion increased with pressure as well as temperature. Such films (Fe_2O_3) and (CuO), therefore, do not make cladding impossible, although their presence is obviously undesirable. A relatively recent and effective method of removing undesirable surface layers is the use of a reducing atmosphere at a high temperature. Another technique is to use shear forces such as those set up by twisting, upsetting in a press, or hot rolling two metals together. The shear forces cause any surface films to break up and permit metal to metal contact to be established.

Solid-Phase Cladding

If cladding is to be carried out in the solid phase, the metals are placed in contact, heated to a temperature below the solidus of both and exposed to pressure. This principle is practised in the two processes referred to here as " roll cladding " and " pressure cladding."

Roll cladding is generally preferred and is of a more straightforward character than pressure cladding. This is especially true if the clad metals are to be supplied as plate. The two metals are first thoroughly cleaned, mechanically and chemically, by grinding and shot- or sand-blasting, and subsequent pickling.

The next step is the assembly of the " sandwiches " from which the clad plate is to be rolled. The base metal may be clad on one or both sides depending on its ultimate use. Excessive oxidation is undesirable when preheating the sandwich for hot rolling, because it is often responsible for bad bonding, especially at the corners of the sandwich cake. Particular care has, therefore, to be taken when assembling the sandwich. There are many different methods of preventing oxidation of the surface on which the actual cladding takes place.

An old method, which is still successfully used in some works on the Continent, consists of wrapping the assembled sandwich in a fully annealed steel sheet of very thin gauge (0·20 to 0·27 mm., i.e., 0·008 to 0·011 in.). This method, however, suffers from two important disadvantages. Firstly, the cost of cladding is considerably increased and, secondly, the handling difficulties with large slabs are insurmountable. If large quantities of clad plate are to be turned out, a considerable stock of wrapping sheeting has to be kept, and this may prove difficult if it has to be purchased outside.
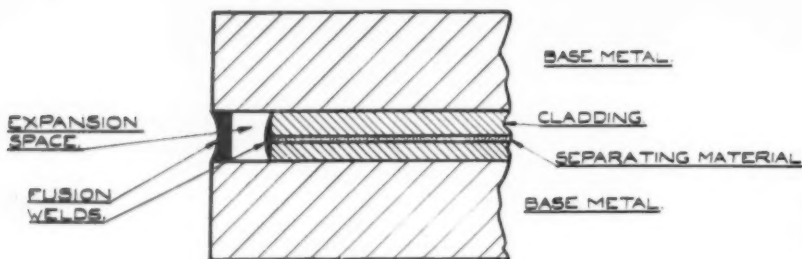
Fig. 1.—Assembly of single clad sandwiches.

Fig. 2.—" Framed " metal sandwich.

In the production of clad plate by this method, it has to be borne in mind that the very thin steel sheet wrapping tends to burn through if one preheats for a relatively long time at a high temperature. Despite all these disadvantages, wrapping the sandwich in steel sheet guarantees a very good product if small size cakes are rolled. The writer has successfully hot rolled many tons of copper-nickel-clad mild steel plate from wrapped sandwiches of small size (24 × 10 × 1 in.).

An alternative method of sealing off the surfaces is by welding the sandwich around the edges. When cladding steel with stainless steel this method is used. If the stainless-clad steel plate is to be clad on one side only, a composite of two sandwiches is rolled. Fig. 1 shows how the sandwiches are put together. The two sheets of surface metal are welded together with separating material between them. After cleaning the surfaces they are placed between slightly larger steel slabs, which are also fusion welded at the edges. The composite is preheated and rolled. After rolling, the edges are trimmed off and the two plates, clad on one side only, can be processed further. Because of the difference between the coefficients of expansion of mild and stainless steel an appropriate expansion space has to be left between the edges of the surface metal and those of the base metal.

A third method of assembly makes use of a flux. The sandwich is assembled as mentioned above, but an even layer of flux is first put on the cladding surfaces. The flux protects the faces from oxidation when the sandwich is preheated and spreads when it is rolled thus making a proper weld possible. If, instead of a flux, a foil of low melting metal, which acts as a solder, is used, the process then becomes liquid-phase cladding.

A more recent method is to preheat the sandwiches in a reducing atmosphere and pass them straight from the furnace into the rolling mill.

In cases where the composites are not wrapped in a steel sheet, they are held together by steel wire or by a frame. Fig. 2 shows such a " framed " sandwich.

Roll Cladding

After assembly, the sandwich is preheated, and it is important to let it soak well in order to obtain uniform bonding over the whole surface. The rolling temperature should not exceed the hot-rolling temperature of the lower melting point metal. The rolling itself is straightforward hot rolling, and after the first pass, areas where no cladding has taken place show up as black areas on the red hot surface. This defect cannot be rectified, even if hot rolling is continued. The defective areas occur due to excessive oxidation during preheating or due to contaminant films on the surface of the base metal or the cladding.
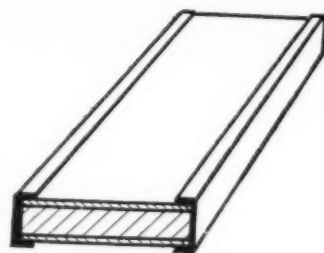
In Germany, aluminium-clad steel strip is produced on a cold-rolling mill. Soft steel strip of deep drawing quality is carefully pickled and afterwards passed through a brushing machine. It is of standard thickness (3·5 mm. = 0·138 in.) and is fed with aluminium strip os 0·2 mm. (0·008 in.) thick to the cold-rolling mill. Thif material is rolled down in one pass from 3·9 mm. to 1·5 mm. (i.e. a reduction of 61·5%). The heat developed under such high pressure enables the aluminium to diffuse into the steel surface, thus giving a secure bond. The strip which is clad on both sides can then be annealed and rolled down further if required. Fig. 3 shows the lay-out of a roll-cladding train introduced in Germany in 1939 for cladding steel with copper. It shows an economical way of roll-cladding plate of different sizes and materials. The sandwiches proceed through the preheating furnace in a reducing atmosphere, and are pushed out through a connecting tunnel, which provides a reducing atmosphere right to the roll gap. This process allows a maximum output with a minimum of labour and cost per unit produced. The use of a preheating furnace makes extensive hot working possible. Thus bigger and heavier stock can be rolled down to an appropriate size and all the cold rolling necessary can be dealt with by one finishing mill. A cold-rolling train is therefore unnecessary. The sandwiches used in this process are held together only by thin steel wire.

Pressure Cladding

A more complicated but effective process for cladding of certain large size stock is pressure cladding.

1. Mill drive
2. 2-high cladding mill
3. 3-high breaking-down mill
4. 3-high finishing mill
5. 2-high cold-rolling mill
6. Preheating furnace
7. Connecting tunnel
8. Pusher
9. Reheating furnace
10. Shears.

Fig. 3.—Cladding train.

The sandwiches are prepared as for roll cladding, and stacked on a carriage over which an electric furnace is lowered. The carriage is subjected to pressure from below, the stacked sandwiches being pressed against the roof of the furnace. The material is heated under pressure in a reducing atmosphere for several hours in order to get a firm bond. Then the stacks are air cooled, the sandwiches cleaned and pre-heated for hot rolling. This method has many disadvantages and is, therefore, only used where there are no facilities to pre-heat large stock in a reducing atmosphere.

A furnace used for pressure cladding is shown in Fig. 4. When stacking the sandwiches a separating material is usually placed between them in order to avoid bonding between the sandwiches. The simplest and best separating material proved to be ordinary wrapping paper.

For materials requiring a high bonding temperature, pressure cladding is unsuitable, because the refractory roof cannot withstand the high pressure at temperatures above 1,000° C. As shown in Fig. 5, the compressive

1. Furnace
2. Carriage
3. Charge
4. Lifting rails
5. Pressure ram

Fig. 4.—Pressure cladding furnace.

strength of fire brick reaches a maximum at about 930° C. falling rapidly as the temperature increases. The writer has processed both brass-clad and copper-nickel-clad steel plate by pressure cladding. Brass-clad strip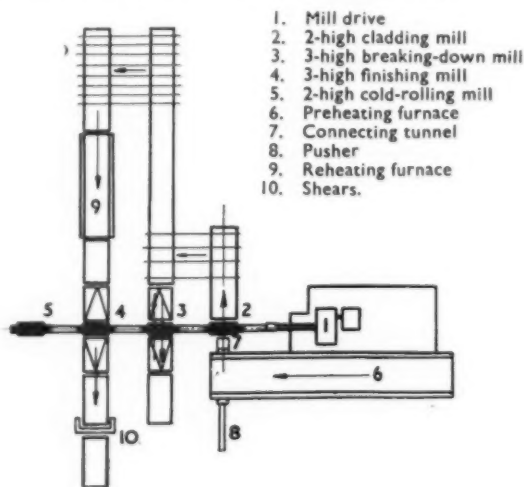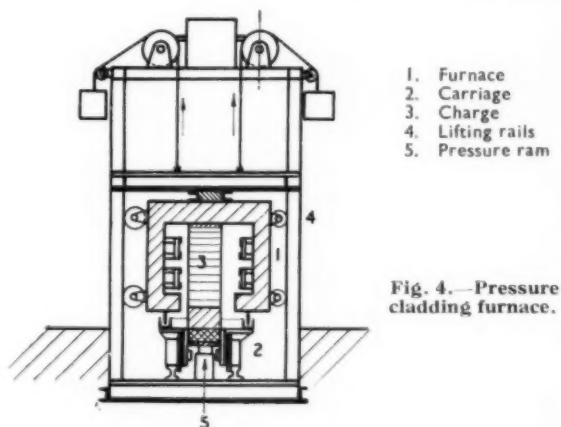 of good quality could be produced without difficulties, while copper-nickel-clad plate proved to be unsuitable for processing by pressure cladding. Due to the lower cladding temperature, brass-clad steel plate could be pressure clad successfully in stacks of 6 sandwiches approximately $1,200 \times 250 \times 80$ mm. ($47 \times 10 \times 3$ in.), at a cladding temperature of 860° C. At this temperature, the compressive strength of fire brick is, as shown in Fig. 5, 1,150 lb./sq.in. When pressure cladding copper-nickel on to steel at 1,050° C., the roof of the furnace would collapse under the pressure since the compressive strength of the brick work is only 450 lb./sq.in. at this temperature.

Liquid-Phase Cladding

If one metal is cast onto another metal, the process is called liquid-phase cladding. We have already mentioned one method of liquid-phase cladding, i.e., where the layers are bonded by means of a solder in the form of foil.

Liquid-phase cladding has until now been used mostly for the production of clad wire or rod. When producing aluminium-clad Duralumin sheets in order to increase
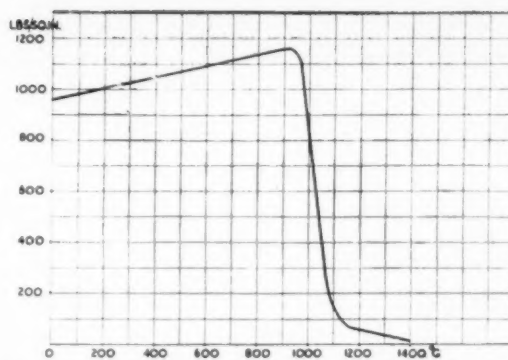
Fig. 5.—Effect of temperature on the compressive strength of firebrick.

the corrosion resistance on the surface, the " casting on " process is sometimes preferred to roll cladding, because of the easier bonding. Roll cladding of this material is rather difficult because of the very adherent oxide film. Duralumin is cast between two aluminium sheets and then hot rolled.

For the production of large quantities of clad wire casting on by continuous casting is suggested. There are two methods of doing so, as shown in Fig. 6; we may call the two processes continuous and semi-continuous cast cladding.

Semi-continuous cast cladding could be carried out by the usual type of continuous or semi-continuous casting machine. A continuous or semi-continuous cast bloom of basic metal is lowered through the mould of a second casting machine as the cladding metal is cast around it. (Fig. 6a).

If the blooms or cakes are cast clad continuously, casting must take place at two different levels. The basis metal is cast on the upper floor and the surface metal cast around the bloom on the lower floor, the clad bloom being cut in lengths by a saw on the ground floor. Fig. 6b shows a sketch of a continuous cast cladding plant.

When cladding semi-continuously, the base metal bloom or cake is lowered into the mould and the surface metal cast around it. The speeds of casting and lowering the basis metal bloom must be adjusted to the speed of solidification of the surface metal. The bloom or cake is then cut into billets or slabs by a mobile billet saw, which moves downwards at the same speed as the bloom.

Continuous cladding is performed in a similar way. The base metal is cast continuously on the second floor, the bloom being lowered to the first floor where the surface metal is cast around it. The composite bloom is then cut into billets by a mobile saw, as described for semi-continuous cast cladding.

Manufacture of Clad Wire and Tube

Cladding of rod and wire is carried out, as already mentioned, by casting the surface metal around a base metal billet or casting the base metal into a hollow billet which consists of the surface metal. Copper clad steel wire is produced by casting the copper around a steel billet. The composite billet is then hot rolled and the rod drawn as ordinary steel wire.

Another method of cladding rod is to draw the surface metal as tube tightly on the base metal rod, anneal at cladding temperature and draw again. This is repeated
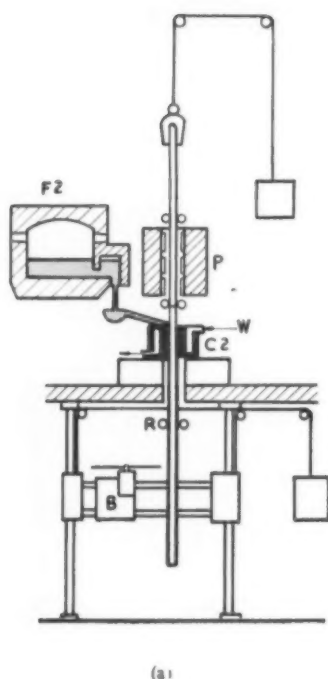
F1 Melting furnace for base metal
F2 Melting furnace for surface metal
C1 Casting machine for base metal
C2 Casting machine for surface metal

B Mobile billet saw
P Preheating jacket
W Cooling water

(b)

Fig. 6.—(a) **Semi-continuous cast cladding; (b) Continuous cast cladding.**
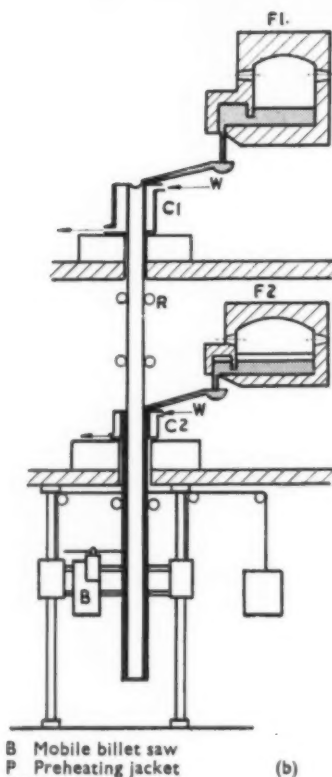
until the composite has the desired size. The larger the number of passes that are involved, the better will be the bond. The same process is used when cladding tube. With every anneal some diffusion between the two metals takes place, the bond becoming firmer after each pass.

The Properties of Clad Metals

The aim of cladding is usually the production of a corrosion resistant material on a base metal of adequate strength, and with relatively thin coatings, the mechanical properties are those of the base metal, with the exception of surface hardness, which is that of the cladding metal. Every effort is made to produce satisfactory bonding, the bonding strength being generally tested by a tensile test. Unsatisfactory bonding is shown up by the separation of the cladding from the base metal at the " neck " of the test piece when pulled in a tensile machine.

Scrap Recovery

The total scrap produced in the manufacture of clad metals may amount to as much as 50%, according to the type of product manufactured. Some composite metals cannot be recovered economically, but others can be melted down and used as alloys or master alloys with low contents of certain constituents. Copper-clad steel scrap, for instance, can be used in making castings which can be precipitation hardened to some extent ; copper

also contributes to corrosion resistance in steel. Brass clad scrap obviously presents a difficult problem, but non-ferrous-clad non-ferrous metals can usually be recovered as alloys.

There is no detailed information available as to the different processes for the recovery or useful application of clad metal scrap. Some firms, which produce composite metals on a commercial basis, sell their scrap. Others recover it themselves and may find in it quite a profitable side line, but this depends entirely on the type of clad metals produced.

The scrap recovery of metals is a problem which is partly responsible for the reluctance of many firms to produce clad metals. It is, however, possible that in the near future more firms may take up cladding, due to the shortage of certain metals, especially where corrosion resistant material is required. For containers of corrosive chemicals, for instance, a clad steel may serve the purpose just as well as, and be cheaper than, stainless steel. Cladding is also cheaper and more reliable than electroplating, where large articles of wrought metal have to be provided with a protective coating.

Acknowledgment

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The Royal Society

THE following have been elected Officers and Council of The Royal Society for the ensuing year :

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Some Impressions of Metallurgical Education in the U.S.A.

By K. M. Entwistle, Ph.D., M.Sc.

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As a member of an O.E.E.C. Mission studying Metallurgical Education in the U.S.A., the author had the opportunity of visiting a number of institutions providing metallurgical training and of discussing the differences in British and American methods. In this article, he outlines some of the impressions gained during the course of the visit.

IN this article, the author presents some personal impressions gained as a member of a Mission studying Metallurgical Education in the United States of America. This was one of several Missions organised at the same time by the American Society for Metals, in conjunction with the Organisation for European Economic Co-operation. The opinions stated herein must be regarded as those of the writer and in no way represent the agreed findings of the members of the party, which will be published shortly as an O.E.E.C. report. The group comprised seven members and visited 19 institutions during a four-week period ; the short time which this itinerary allowed at each place was insufficient for any detailed study, so that the impressions recorded are necessarily of a general nature. In this connection the author is tempted to extend the opinion of Pope, that " a little learning is a dangerous thing," to include the corresponding dangers of making inferences following too little observation of the methods used for the dissemination of learning.

Two opportunities arose for the study of United States metallurgical education ; first, during the four-weeks tour of institutions and subsequently, during the week of the World Metallurgical Congress in Detroit, when two meetings were arranged by the American Society for Metals between the Mission members and about 40 representative leaders of American metallurgical education from all parts of the country. It was a great privilege to meet such a large and authoritative group, and the discussions which took place were of great value, particularly for obtaining concerted opinions on controversial subjects, and further clarifying queries which arose out of the visits.

Educational Institutions

The visits were made to institutions in three categories
(*i*) Universities, or schools of similar status, providing courses leading to degrees in metallurgical subjects ;
(*ii*) Establishments primarily interested in training engineers, but giving some incidental training in metallurgy ;
(*iii*) Government and private research organisations.
Most of the visits were made to departments in category (*i*), and the educational activities observed in (*iii*) were generally very restricted.

American universities may be divided into two groups, according to the origin of their financial support. The first group derives all its income from students' fees, endowments and sponsored research contracts, and receives neither Federal nor State support. Most of the older universities such as Harvard, Yale, Columbia and Lehigh are of this class. The second group comprises the land-grant colleges which were set up after the Land-Grant Act of 1862, by which Federal land was granted to each State and subsequently sold " for the endowment, support and maintainance of at least one college (in each State) where the leading object shall be, without excluding other scientific and classical studies, and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts . . ." Of the 69 colleges set up, 17 are exclusively for the education of negroes and 26 have developed into State universities, which receive about half of their income from State taxation. Admission is not restricted to residents of the State, but students from other States are required to pay tuition fees of about \$200 a year, whereas State students pay nothing. Three universities of this kind were visited, Purdue University (the land-grant college of Indiana), Ohio State University and the University of Michigan, and were found to be characterised by pleasant modern buildings, spaciously disposed about pleasant campus, and housing a student population of about 25,000 each. Massachusetts Institute of Technology benefited under the Act, but this now forms a trivial fraction of its income. The originally-intended agricultural bias of the land-grant colleges persists only in the agricultural areas, as, for example, at Kansas State College, but in most other State universities a complete range of subjects is offered.

Of 56 schools in the country which give metallurgical instruction, about 35 grant metallurgical degrees recognised by the Engineers' Council for Professional Development—a body which accredits degree courses on the basis of a full study, by a sub-committee, of facilities, policy and curriculum. There is a marked difference in emphasis between schools to the east and west of the Mississippi river. The western schools, for example, Colorado School of Mines, Montana School of Mines and Washington State College, teach principally mining and extraction metallurgy, reflecting the character of the local metallurgical industry. The eastern schools give more consideration to physical metallurgy and engineering applications of the refined metal. No school in the western region was visited.

Students enter a first degree course* from high school at about 18 years of age, that is after 12 years at school. It seems that the standard in pure science required of an

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* The use of the term first degree course is deliberately chosen because all first degrees are not designated bachelor, as, for example, at Stevens Institute, N.J., where the degree is Mechanical Engineer.

entrant in metallurgical subjects is between 18 months and 2 years behind his British counterpart. One reason for this is that at all levels more of the American high school timetable is taken up with subjects classified as " humanities," such as history, civics and literature, and the specialisation introduced into the British sixth-form work is absent. The policy necessitates an undergraduate course of four and sometimes five years duration.

Common First Year Course

The first year time table is common to a large group of students, for example all the College of Engineering, who take a uniform basic science course with " humanities." The students' activities during this freshman year are directed by what is often called the Liberal Arts College, and only at the end of the year, or in some cases at the end of the second or sophomore year, need he elect for his particular degree subject. If this option is metallurgical engineering, he will then be supervised by the Metallurgy Department. The subjects classified as humanities—broadly speaking the more cultural and non-scientific subjects—form an important part of the first degree course, occupying about a quarter of the class time. At least two universities, Ohio State and Cornell, have increased their course from four to five years, and allocated all the additional time to humanities and elective subjects.

Metallurgy departments recently experienced difficulty in attracting their full quota of entrants, because students both at high school and in Liberal Arts Colleges were unaware of either the existence of, or the opportunities within, the metallurgical profession. The situation has been improved by publicity campaigns, with lectures and exhibits to potential students. The assistance of the American Society for Metals was enlisted in the production and circulation of a brochure " Your Career in the Metallurgy Profession," which outlines the range of interests covered by metallurgy, and points to the shortage of well-trained metallurgists.

Allied to this question of publicity is that of selection; tests of a psychological nature are not so widespread as may be imagined, but the Metallurgy Department of New York University has recently developed an experimental questioniare. This is filled up by the candidate before interview and, it is claimed, helps the interviewer by providing a picture of the student's background and interests beforehand.

Philosophy of Education

The metallurgy courses leading to the first degree were found to differ widely; this is related to differences in what Americans refer to as their " philosophy of education." On one point, however, there is complete agreement; that a pre-requisite to any metallurgical instruction is a sound knowledge of basic science. In consequence, metallurgy is included in only the third and fourth years at, for example, Yale and Columbia, and apart from a short introductory second year course, at M.I.T. and Carnegie Institute of Technology. Harvard excludes the subject entirely from its first degree courses and teaches it only in the post-graduate school. This policy has much to recommend it for training students for fundamental research appointments, but other schools feel that their function is to train men for executive positions in industry, for which a more technological approach and a higher proportion of

metallurgy in the course is desirable. The courses at British universities have a greater proportion of specifically metallurgical subjects than any of the American courses encountered. This means that the British student has more opportunity for advance in this direction, but not necessarily that his metallurgical knowledge, a quality neither easily defined nor measured, is greater. It would be agreed on both sides of the Atlantic that the important criterion by which learning is judged is by the student's approach to the subject, not by the extent of his possibly disconnected store of facts. From this point of view, the amount of metallurgical instruction is less important than its manner of presentation.

Each year of the course is split up into two equal semesters, and at the end of each semester a number of credit-hours, evaluated in proportion to relative importance, is given for satisfactory completion of a lecture or laboratory course; for example, 3 credit hours may be given for a one-semester strength of materials course. One condition for the award of the degree is the accumulation of say 160 credit hours during the four undergraduate years. It is customary to set homework assignments which are integrated with the lecture courses, and may take the form of calculations or duplicated sets of questions requiring short answers. One school estimated that its students were occupied in set work, lectures and laboratory courses for about 50 hours a week; another estimated 55 hours, but admitted that the brighter students would spend less. This appears to leave little free time for individual work and general reading.

Non-Metallurgical Subjects

The following selected figures relate to the subject content of metallurgy courses in 21 eastern schools and are abstracted from a more extensive list compiled by H. L. Walker (A.I.M.E., 1940); the percentage figures are based on the proportion of the 21 schools giving courses in the subjects indicated.

English, 100%.
Foreign Language, 28%.
Economics, 81%.
Electrical Engineering, 90·5%.
Machine Drawing, 100%.
Forge and Pattern Shop Practice, 48%.
Chemical Analysis, 100%.
Pyrometry, 23·8%.
Thermodynamics, 38%.
X-Ray Crystallography, 28%.

The list has been chosen to illustrate three points: (1) the widespread inclusion of non-metallurgical subjects; (2) the relatively restricted instruction in thermodynamics and X-ray crystallography; and (3) the inclusion of engineering subjects. It is significant that metallurgy generally finds a place in a college or school of engineering, sometimes as an off-shoot of chemical engineering. Degrees are usually in metallurgical or mineral engineering and in no case was the subject found associated with pure science departments. On several occasions department heads explained their conception of metallurgy as the union of science and engineering; the fundamental principles are treated as pure science but their application is engineering. This leads to a realistic approach and constitutes a difference between the British and American attitude, British universities concentrating more on fundamentals and

leaving the engineering aspects to be acquired in industry following graduation.

High Standard of Equipment

The range of equipment for practical work and class demonstrations was found to be very impressive : this may be the result of far-sighted local manufacturers or persuasiveness on the part of the department staff who manage to convince firms that an out-of-date piece of equipment forms a poor advertisement. Practical courses differ from those in Great Britain, mainly by the inclusion of experiments on large-scale equipment : some schools had recently installed complete mechanised foundries with a cupola of capacity 3 tons an hour, whilst others had a wide range of welding equipment and extensive machine shops. It was not possible in the time available to assess the full value of instruction on equipment of this kind, but it is rather out of place in the British idea of a university.

In the final year, some schools require a report based on a short practical research exercise ; it is agreed that here the choice of problem is important. Other schools require a literature survey, or a solution of an industrial type of problem, for example the design or layout of a plant for the manufacture of a particular component, which calls on a wide field of metallurgical knowledge.

Sandwich Courses

Co-operative or Sandwich Courses are available at some universities, notably at Purdue in metallurgical engineering and Northcourse is University in engineering. In the latter case the Western for five years. The first 18 months is spent at the university, and then the class divides and spends alternate 3-month periods in industry and college, so giving every student about $3\frac{1}{2}$ years at the university and $1\frac{1}{2}$ years industrial training. Lectures are thus given twice a year and there is no long vacation. The co-operating firm pays the student for his period in the works.

Several universities offer a five-year course, not necessarily all at the same school, leading to a combined arts and science degree.

The marked advantage of the possession of a degree in securing higher level employment in the United States is unquestionable. For this reason, many men make considerable sacrifices in order to study for a degree. At Lehigh University, Bethlehem, for example, at least five undergraduates attend a full-time degree course whilst working full hours in local steel works on night or morning shifts. It is usual for most students to earn money by doing regular part-time work during the course, and this situation is not a temporary result of an increased proportion of ex-servicemen.

The cost of a degree course varies between the private and State universities, because a State resident in the latter case pays no tuition fees. The necessary expenses, neglecting travel and entertainment, are estimated at $1650 for a 37-week year at M.I.T., about $1,700 at Columbia University, and $1,200 at Illinois Institute of Technology ; these figures are typical of the private universities, excluding Harvard and Yale. A State resident at a State university would pay about $700 a year if in university accommodation. Possibly the best indication of the scale of these figures is to compare them with the salary a metallurgist may expect after graduation, which for industrial employment may be about $3,000 per year initially, or for the 5th grade in Federal scientific service $3,100 a year.

Post Graduate Degrees

Most of the departments visited had facilities for study for master and doctorate degrees. A good first degree is essential for entry to these courses and at least one school, the University of Michigan, has a probationary period of 21 days during which the student works on a set problem, and his admission depends on his performance.

The master's degree involves about one year's attendance at set courses and subsequent examination : a short research project may be undertaken but in most cases is a subsidiary requirement. This form of higher degree course appears to stifle initiative and postpone the development of independent thought : the course leading to the first degree should be adequate to equip the student so that he is in a position to further his metallurgical education on his own initiative, albeit with facilities for discussion with experts in particular fields.

The professional qualification of Metallurgical Engineer (M.E.) is awarded to applicants who have spent a specified period in a responsible position in industry and submit a thesis on some design or process problem.

The degree of Ph.D. or its equivalent D.Sc. or D.Eng. is roughly equal in standard to the British Ph.D. There is no equivalent to the faculty doctorates of the British universities, for example D.Sc. or D.Met. The U.S. Ph.D. requirements include attendance at selected courses of lectures and submission of a thesis based on original research work, which is possibly more closely supervised than here. Libraries have complete published lists of all doctorate thesis, a procedure which might well be copied in this country, where much valuable information in this form remains unpublished and unpublicised in university archives.

Sponsored Research

An outstanding feature of U.S. university research work is the extent to which it is sponsored by extra-mural agencies. Research contracts are accepted from government departments, such as the Office of Naval Research and the Atomic Energy Commission, and from industrial organisations. This income allows the maintainance of a wide range of research interests, the acquisition of an impressive amount of apparatus and, most important from the educational point of view, the provision of subsistence grants for research students. Such funds, combined with scholarships and teaching assistanceships, allow several schools to claim that all suitable candidates wishing to take a higher degree course can be offered financial support. The volume of sponsored research reaches its peak at the Massachusetts Institute of Technology, where the total research budget is $10,000,000 per annum, of which $1,500,000 is for metallurgy. It is of interest to compare these figures with the $25,000,000 budget of the National Bureau of Standards, one of the principal Federal research establishments, and the $8,000,000 per annum budget of the Battelle Memorial Institute.

The attractive incomes derived from research contracts may lead to the acceptance of work of an *ad hoc* or routine nature with little educational value. This temptation constitutes a danger which is generally, but not always, resisted, but the system has much to recommend it if the sponsors accept wide terms of reference. It may be difficult to preserve an atmosphere conducive to good fundamental work if results and

reports are required at frequent intervals, but it was clear in much of the work which the party was privileged to see that the sponsors are generally most far-sighted in this connection, and support projects of a fundamental nature, whilst allowing considerable freedom in the development of the research.

Contracts from industrial organisations serve to maintain close contact between universities and industry, with mutual benefit. Many schools expressed their belief in the importance of such contact for teaching and research staff, since this keeps them up to date with technical developments and maintains a clear appreciation of the nature of the world in which most of their graduates will eventually find employment. American industry, with its high degree of mass production and control, appreciates the value of employing university-trained men both in design and planning offices and in the shops, and the universities are alive to their responsibility for supplying suitably trained personnel. Further industrial contacts are maintained by a policy adopted by most U.S. university departments which encourages their staff to undertake consulting work, generally up to about one day a week during the academic year and more extensively during the long vacation. Income from such work, which is deliberately charged at the market price to eliminate any danger of exploiting " cheap labour," makes staff salaries more flexible and helps to keep first-class men in university employment. Even so, it was admitted on several occasions that valuable staff members leave in the face of attractive industrial offers.

Administration

The problem of the administrative duties of the head of a university department and his academic staff is solved realistically by appointing an administrative head, or chairman, in addition to the academic head or senior professor. The chairman is often a metallurgist, and with his own staff he looks after records, book-keeping, orders, admissions and similar tasks, so leaving the academic head to devote his undivided attention to teaching and the direction of research.

Many of the universities awarding degrees in metallurgy held part-time courses in the evenings. No qualification other than a degree can be gained from attendance at these, there being no equivalent in the U.S., for example, to the National Certificates of this country. Nine to eleven years is required to obtain a degree by part-time study, as at the Carnegie Institute of Technology, for example, but in practice students eventually contrive to attend full-time in order to complete the latter part of the course in a shorter period. In other schools it is possible to cover only the first and second years of the first degree-course by evening class attendance. No case was encountered of a firm allowing junior staff to study (with pay) for a degree or other qualification during part of their working time. At the Illinois Institute of Technology, as at other institutions, evening lecture courses are given primarily to explain current developments in more fundamental fields to industrial metallurgists.

Social and Athletic Life

The social and athletic life in U.S. universities is as active as reports allege. A high percentage of students live on or near the campus in university dormitories or fraternity houses. The latter have recently become more popular following a tendency towards a reduction of the " ceremonial rites " associated with entry into the secret societies of the fraternities. The extent to which former students, or Alumini, provide social and recreational facilities is remarkable ; the new graduates residence at Harvard is an outstanding example, both in accommodation and architecture, of what can be done in this manner.

Industrial Education

In addition to metallurgical teaching in universities, the educational activities of leading motor-vehicle manufacturers were observed with great interest. The General Motors Corporation runs a five-year sandwich course for training students employed by the Corporation, or by its distributors, for positions of responsibility in the industry. The first four years of the course is held for alternate four-week periods at the General Motors Institute and in a G.M. plant of the student's choice, and leads to a degree of Bachelor of Automotive Engineering, granted by the Institute and licensed by the State of Michigan. Tuition costs are $390 a year, but the student receives $240 a month for the periods in the plant. The course comprises primarily science and engineering, but includes some metallurgy in each of the first four years, covering metal processing, physical metallurgy, heat treatment, foundry work and inspection. The whole of the final year is spent studying some problem in the works or laboratories. Students interested in metallurgy may choose a metallurgical project, as for example " Relative effects of various types of quenching on the production of graphitised cast iron." The annual rate of graduation is about 350 students.

The Chrysler Institute of Engineering is the educational section of the Engineering Division of the Chrysler Corporation. It is licensed to grant all degrees, but the most popular is the Master of Automotive Engineering, which involves a two-year course, open to students with a first degree who graduated in the top quarter of their year. The students spend $1\frac{1}{2}$ hours a day at lectures and $6\frac{1}{2}$ hours a day on assignments as part of the works engineering staff. The amount of metallurgical instruction is small.

The Ford Trade School is independent of, but works in close co-operation with, the Ford Motor Company. Boys of about 14 years of age from high school are given pre-apprentice training in a four-year course leading, at the age of 18, to a high school diploma. Teaching is given in alternate periods of one week in the classroom and two weeks workshop experience. Class work includes elementary metallurgy, covering steelmaking, metallography and heat treatment. The boys receive a free hot lunch at noon and are paid from $190 to $265 a half year, dependent on age and attainment. The school is supported entirely by the sale to the Ford Motor Company of tools and components which have passed normal inspection and are made or repaired by the boys. Between 300 and 350 boys pass out of the school each year and most of them enter a $3\frac{1}{2}$–4 year apprentice course on a pay scale of $1·61$\frac{1}{2}$ an hour.

In retrospect it seems an affront to U.S. metallurgical education to hope to obtain a fair impression of its many facets, generally widely separated geographically, in a tour of as short a duration as four weeks. The tour was not, indeed could not be, all-embracing and completely representative, and yet the author feels to have been able to form a fair general impression of important

aspects of the educational system. The credit for this should be divided between the American Society for Metals, for the careful thought and effort given to the planning of the itinerary, and to the staffs of the departments visited, who were extremely co-operative in arranging the day's proceedings to allow the party to see the things which interested it most, and were most helpful in answering queries. The informal discussions which always formed a valuable part of every visit invariably brought out the considerable thought which the U.S. teaching staff gives to its educational problems, and, at the same time, proved how much the present healthy state of U.S. metallurgical education owes to its competent and enterprising staff and leaders.

A Successful Experiment with Broaches
By W. Jubb, Assoc. Met., A.I.M.

IN normal practice, the material used for the manufacture of broaches is one or other of the high-speed tool steels available, usually the 18% tungsten, or the 14% tungsten, — 4% vanadium analysis, and the service obtained from purchased broaches would not appear to justify experiment with any other material.

The opportunity arose, however, when a vital broach was broken accidentally. No spares were available and delivery of a new set was a matter of several months. The only furnaces large enough to heat-treat the broaches were incapable of attaining the requisite temperatures for high-speed steel, which meant that some other material would have to be used.

The first material selected was En. 32A, the standard carbon case-hardening steel for small sections, having an analysis specification : Carbon 0·15% max., Manganese 0·40/0·70%, Silicon 0·50/0·35%, Sulphur 0·05% max., Phosphorous 0·05% max. On this steel a case hardness of 820/840 D.P.N. was obtained which, for all practical purposes, is equivalent to the hardness of high-speed steel.

However, three defects were apparent on putting the broaches into service :—

(a) The case was too brittle and the cutting edge tended to chip readily ;

(b) The core strength was too low and the load on the cutting edge compressed the core and caused collapse of the case ;

(c) Failure occurred by tensile breakage due to the low core strength and general brittleness.

Accordingly, a complete set of broaches was made in En. 36, 3% nickel-chromium case-hardening steel, with the object of obtaining a case of slightly lower hardness, but increased toughness, and at the same time, a much stronger core. This material had the analysis specification : Carbon 0·18% max., Manganese 0·30/0·60%, Nickel 3·00/3·75%, Chromium 0·60/1·10%.

After rough machining, the broaches were annealed at 650° C. to remove machining strains, and to reduce their liability to distort during the subsequent heat treatment. Finish machining then followed, leaving an allowance of approximately 0·005 in. for the finish grinding. Next, the broaches were pack carburised at 900° C. to give them a case from 0·035 to 0·040 in. deep, and cooled slowly in the box.

Refining at a temperature of 860° to 870° C. and quenching vertically in an oil bath then followed to obtain the optimum properties in the core, after which reheating to 780° C. was carried out and the broaches were again quenched vertically in oil to harden the case. This was followed by reheating to 100° to 120° C. and straightening, the reheating affording a slight tempering of the case prior to the finish grinding operation.

It was found that on a 2 ft. 6 in. length, the maximum distortion could be controlled to 0·005/0·007 in. on quenching, and warming to 100° C. or so, as already mentioned, allowed this to be reduced to 0·001/0·002 in. by press straightening. The case-hardness was fairly consistent at 790/810 D.P.N.

The component to be broached was a forging weighing approximately 5 lbs. A rectangular slot was required, $\frac{9}{16} \times 1\frac{1}{16} \times 4\frac{1}{2}$ in. deep, and since only the ends of the $\frac{9}{16} \times 1\frac{1}{16}$ in. section were important, a $\frac{7}{8}$ in. hole was first drilled through and reamered to remove the maximum possible amount of metal before broaching. Four broaches comprised the set, each of an overall length of 2 ft. 6 in., with a cutting length of 1 ft. 9 in., and each tooth removed approximately 0·002 in. The forgings were in the annealed condition, made from either En. 17 manganese-molybdenum steel, En. 19 chromium-molybdenum, with a few in En. 39B (the nickel-chromium-molybdenum case-hardening steel) having the analyses as set out in Table I.

TABLE I.—COMPOSITION OF FORGING STEELS

	En. 17	En. 19	En. 39B
Carbon %	0·30/0·40	0·35/0·45	0·12/0·18
Manganese %	1·30/1·80	0·50/0·80	0·50 max.
Nickel %	—	—	3·80/4·50
Chromium %	—	0·90/1·50	1·00/1·40
Molybdenum %	0·35/0·45	0·20/0·40	0·15/0·35
Brinell Hardness	200/220	200/220	230/260

The output of this set of broaches was 10,283 components without even a re-grind. Some wear certainly took place, but the components were still within the specified tolerances. Unfortunately, broach No. 4 was broken by mechanical trouble before its useful life was finished.

Several other sets of broaches were manufactured, up to 2¼ in. square, and these gave very good service, although not doing, by any means, the same amount of work as those described previously.

In a high-speed broach, the material is, to all intents and purposes, of the same hardness throughout, and has sufficient hardness and toughness to cut and to support the edge while cutting. A case-hardened steel has sufficient hardness to cut similar materials but the standard carbon case-hardening steel does not possess the core strength to back-up the cutting edge. An alloy steel of the type used, however, would appear to have a stronger and tougher case which is more resistant to chipping, whilst the increased core strength is sufficient to support the cutting edge.

The experiment, carried out with the limited heat-treatment facilities available, proved highly successful and whilst drawbacks may arise, the evidence warrants further experiment.

Some Experiences in the Use of Chrome-Magnesite Refractories

By G. Reginald Bashforth, F.I.M.

Although the " all-basic " open-hearth furnace for steelmaking is still in the experimental stage, both in this country and the U.S.A., basic refractories have been used fairly extensively in various parts of the furnace. Experience in the use of chrome-magnesite refractories is related to the structure and constitution of the materials.

MY earliest experience of chrome-magnesite refractories dates back to 1930, when the Radex brick was first introduced into this country. Owing to the success of initial trials, it was decided to adopt this type of refractory for the port construction of the open-hearth furnaces at the firm with which the author was associated. These furnaces were old fashioned, being very short between the ports, whilst the ports themselves were also short. In order to assure reasonable length of life, it was eventually found essential to employ chrome-magnesite bricks in the port construction.

After Munich, the probability of war demanded alternative sources of supply, and it was decided to test the various brands of chrome-magnesite refractories at that time available. The various bricks tested are shown in Table I under a code, whilst the results in practice are given in Table II. For purposes of comparison, the longest life obtained is referred to as 100% efficiency, and the average life given by the other bricks is shown as a percentage of this figure.

Microscopical Examination of Chrome-Magnesite Bricks

A comparison of the analysis, shown in Table I, with the results obtained in practice, as shown in Table II, does indicate a fairly definite trend. The best results in practice were attained when the lime and silica contents of the bricks were low. In spite of this trend, however, it must be agreed that the chemical analysis bears little relationship to the performance of the bricks in service. It was, therefore, decided to make a microscopical examination of the various types of bricks included in this trial.

The photomicrographs are shown in Figs. 1–5 and the following comments may be made on the various specimens.

Sample A1. This specimen shows a deep red chromite, generally in an advanced degree of disintegration. This mineral is confined to the coarse and medium fractions of the grading, whereas the chocolate brown magnesia is essentially in the fine fractions, although isolated medium size grains are visible. It is interesting to observe the surrounding highly birefringent rims around the coarse chromite, as well as the " nests " of this phase, which are believed to be a magnesium silicate mineral. These nests are considered to be composed of silicate minerals intentionally added to provide a bond or gangue and which have not been separated from the original chrome ore. The ruby red colour of the chromite is characteristic of Grecian ore.

TABLE I.—PARTICULARS OF CHROME-MAGNESITE BRICKS TESTED.

Brick Code	A.1	A.2	A.3	A.4	A.5
Grain	Medium	Medium to Fine	Fine	Irregular	Irregular
Appearance	Purple with White Inclusions	Light Brown	Purple to Dark Brown	Dark Brown Patchy	Light Brown
Analysis					
SiO_2 %	3·30	4·50	5·00	8·60	9·90
Iron Oxide % ..	10·94	12·00	11·80	13·26	10·24
Al_2O_3 %	8·19	20·00	16·10	5·90	8·00
CaO %	2·01	1·40	2·58	4·80	1·45
MgO %	45·80	37·56	44·90	52·40	54·60
Cr_2O_3 %	31·30	24·00	19·60	15·00	15·90
Loss on Ignition ..	—	—	—	—	—

TABLE II.—LIFE OF PORTS OBTAINED.

Brick	A.1	A.2	A.3	A.4	A.5
Efficiency % ..	93·4	100	91·3	74·6	64·0

Sample A2. The chromite of this sample is again present in the coarse and medium fractions only, with the magnesite in the fine fraction. The uniform size of the chrome is suggestive of careful grading control. It differs from Sample A1 in that the magnesium silicate bond is evenly distributed throughout the matrix and few " nests " are evident. Both the chromite and the magnesia are more transparent than in Fig. 1. The origin of the chrome ore may be Turkey.

Sample A3. This section very closely resembles Sample A1, though the quantity of birefringent mineral is slightly higher, and the size of the coarser chrome grains is somewhat larger. There is no evidence of magnesia other than in the fine fraction, indicating reasonable grading control. The suggestion is made that the encircling rims of magnesium silicate are due to prolonged heating or to the use of a particular type of chromite.

Sample A4. Two types of chromite can be distinguished in this section, a ruby red (Mediterranean origin) and an opaque type (probably African origin). Magnesia can be identified in both the coarse and fine fractions and also the chromite. The size of the chrome and magnesia grains varies over the whole range, which suggests that grading by mixing the different fractions is not used and it is suggested that the mix is produced by pan milling.

Sample A5. The characteristic feature of the sample is the high proportion of birefringent minerals, usually associated with the chromite grains. A small quantity
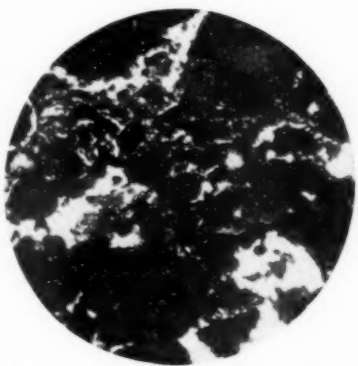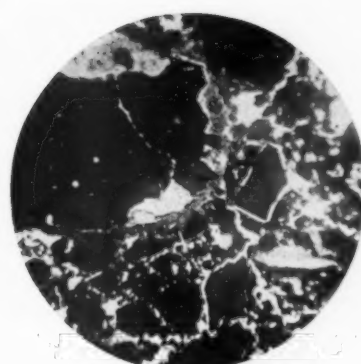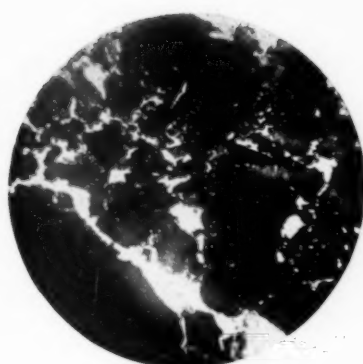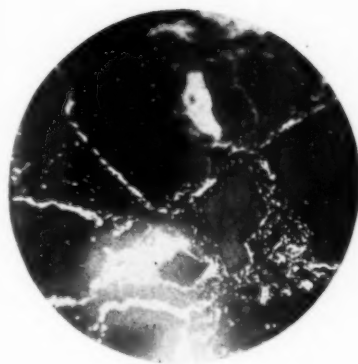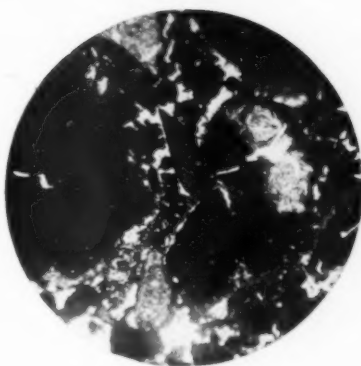
Fig. 1 (top left).—Sample A1.
Fig. 2 (top centre).—Sample A2.
Fig. 3 (top right).—Sample A3.
Fig. 4 (left).—Sample A4.
Fig. 5 (right).—Sample A5.

These micrographs were taken at a magnification of ×35 and reduced ⅓ linear in reproduction.

of opaque chromite can be isolated, as well as occasional grains of magnesia, in the coarse fraction sizes. Some large grains of translucent red chromite are visible, the amount being greater than in Sample A4 but less than Sample A3. The highly silicious chromite is probably of Shetland origin, or magnesium silicate may have been added intentionally to provide a crystalline bond.
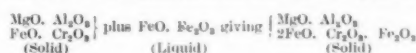
Development of Chrome-Magnesite Refractories

Since the introduction of chrome-magnesite refractories, a considerable amount of research has been conducted into their constitution and properties. They consist of a complex spinel (Fe, Mg) O (Cr, Al, Fe)$_2$O$_3$ together with gangue material which is usually silicious.

It was found that chrome-magnesite bricks prepared from certain ores were mechanically weak and oversize when drawn from the kiln. Experiments demonstrated that chrome ores are readily oxidised, even at temperature as low as 300° C., the ferrous spinel chromite FeO.Cr$_2$O$_3$ and the hercynite FeO.Al$_2$O$_3$ being altered to a solid solution of sesquioxides Fe$_2$O$_3$.Al$_2$O$_3$.Cr$_2$O$_3$. Under reducing conditions, at temperatures over 650° C., these solid solutions are reduced to chromite with a large volume change, which is often as much as 30%.

The ores which were liable to this friability all possessed a ferrous oxide content of over 18% and the tendency to friability can be reduced by selecting an ore with an iron oxide content of less than 15%. It was also shown that the friability and growth could be reduced by increasing the amount of forsterite (2MgO.SiO$_2$) in the matrix by additions of serpentine or olivine.

One great difficulty with this type of refractory is the attainment of high thermal shock resistance coupled with a low bursting tendency in the presence of iron oxide. The best bricks from the aspect of spalling tend to possess an open texture and, hence, are more likely to absorb iron oxide and burst. Chesters[1] suggests that this bursting in the presence of iron oxide is probably due to the solid solution of iron oxide in the chromite :—

$$\begin{matrix} \text{MgO. Al}_2\text{O}_3 \\ \text{FeO. Cr}_2\text{O}_3 \\ \text{(Solid)} \end{matrix} \text{plus FeO. Fe}_2\text{O}_3 \text{ giving} \begin{matrix} \text{MgO. Al}_2\text{O}_3 \\ \text{2FeO. Cr}_2\text{O}_3 \text{. Fe}_2\text{O}_3 \\ \text{(Solid)} \end{matrix}$$

Micrographs show that the chromite crystals grow as the mixed spinels form on the surface and diffuse inwards. This growth may result in a linear expansion of 20%, and, since the furnace structure cannot accommodate such expansion, the face of the brick bursts.

This bursting in the presence of iron oxide, which is considerable even at 1,400° C. and occurs as soon as iron oxide is absorbed, can be controlled by several means. It can be reduced by the addition of various materials, and by regulation of the chrome/magnesite ratio. A considerable amount of research has been carried out on the properties of chrome-magnesite refractories by Hugill and Green[2], Lynam and Chesters[3], and Chesters and Lee[4]. This work appears to confirm that the swelling is due to the solid solution of magnetite in the ismorphous chromite, and that it can be controlled by the chrome/magnesite ratio. Rees[5], discussing possible improvements in the properties of chrome-magnesite bricks, suggests a better chrome/magnesite balance and better grading to secure a lower permeability,

1 Chesters. J. West Scot. I and S. Inst., 1939, **46**, 65-70.
2 Hugill and Green. B.R.R.A. Bull., 1937, **43**, 41.
3 Lynam and Chesters. J. Am. Cer. Soc., 1939, **22**, 97-104.
4 Chesters and Lee. Trans. Cer Soc. 1936-7, **36**, 294.
5 Rees. Proc. Cleveland Inst. Engrs., 1938-1939 (3), 87-105.

which would result in less penetration and, thereby, increased durability.

Chesters[6] shows that high thermal shock resistance can be obtained by controlling the grading; the chrome fractions should be coarse and the magnesite fractions fine in order to obtain the best results. The magnesite usually forms a forsterite bond ($2MgO.SiO_2$) with a high refractoriness, whilst the gangue associated with the chromite has generally a lower refractoriness. Most chrome-magnesite bricks show a high refractoriness under load compared with other basic bricks, but this quality is not as good as silica bricks show in the maintained temperature test.

A recent B.R.R.A.[7] report quotes the following range of analysis and properties of the pre-war Radex E brick, which gave very satisfactory results in certain parts of the open hearth furnace construction.

Analysis: SiO_2 .. .. 3·0% to 9·0%
Al_2O_3 .. .. 2·8% to 14·6%
Fe_2O_3 .. .. 10·1% to 17·3%
Cr_2O_3 .. .. 30·2% to 36·0%
CaO .. .. 0·1% to 2·5%
MgO .. .. 34·6% to 44·5%
Refractoriness under Load (28 lb./sq. in.) to Fail Point:
1,675° C. to 1,740° C.
Apparent Porosity: 19% to 28%—usually about 25%.
Cold Crushing Strength: 2,120 to 3,550 lb./sq. in.

They recommend that the matrix of these bricks should be as near as possible to forsterite composition ($2MgO.SiO_2$) and that lime, which lowers the melting point of the matrix, should be kept low. The chrome ore employed should approximate 3–6% silica, under 15% ferrous oxide and under 1% lime. It is suggested for basic roofs that the alumina content should be fairly high so as to reduce the bursting expansion.

TABLE III.—ANALYSIS OF RECENT CHROME-MAGNESITE BRICKS.

Example	Brick " S "	Brick " C "	Brick " R "
SiO_2 %	5·80	4·50	7·20
Fe_2O_3 %	11·14	15·80	14·50
Al_2O_3 %	8·12	22·40	16·40
CaO %	3·20	tr.	tr.
MnO %	1·88	0·75	0·94
MgO %	42·74	36·05	37·14
Cr_2O_3 %	26·20	19·53	23·44
App. Porosity % ..	23·93	24·29	31·00
Bulk Density.. ..	2·96	2·92	3·22
App. Sp. Gr... ..	4·19	3·86	3·84

Recent Practical Trials

Since the cessation of hostilities, the author has conducted further practical tests and endeavoured to relate these results to the chemical and microscopical constitution of the bricks. The chemical analysis is given in Table III, whilst the microstructure is shown in Figs. 6 to 11.

Brick S appears to have been made from a chromite of comparatively pure large crystals. The general appearance of the section is typified by the upper left section of the photomicrograph Fig. 6. It will be noted that in this area the chromite crystals are practically intact, there having been no disintegration on firing. There is, in this area, a fair amount of forsterite bond as may be seen from photomicrograph Fig. 7, taken in plane polarised light. As far as may be ascertained, this bond is largely constituted of forsterite having the characteristic birefringence in the fourth order red at 0·034 to 0·035 (Ng-Np).

The large grain in Fig. 6 does, however, appear to have disintegrated on firing, but there does not appear

6 Chesters. Iron and Steel, 1940, 13, 214–220.
7 B.R.R.A., Special Publication No. 9, 1947.

to be the same degree of drainage of gangue as in the case of brick C (photomicrograph Fig. 8). The fact that there has been a certain amount of drainage is clear from the photomicrograph of this grain in plane polarised light (Fig. 7), since, in its vicinity, the bond is developed to a marked degree. It is probable that this brick has been prepared from a non-African variety of chromite.

In the photomicrographs of brick C, Figs. 8 and 9, it is very clear that marked disintegration of the chromite grains has occurred, the photomicrographs being typical of the whole section. It will be noted that in the photomicrograph Fig 9, in plane polarised light, the whole of the burst grain is surrounded by an almost continuous wall of forsterite bond. It is probable that the individual chromite crystals originally contained pockets and channels of serpentine gangue which, on firing, have caused the bursting of the grain, with the subsequent drainage of the interior impurity to the grain boundary where, in the presence of excess MgO, forsterite has been formed. It was not evident whether or not monticellite was also present.

Brick R, shown in Figs. 10 and 11, resembles brick S in that it has been prepared from a chromite of large pure crystals, showing little disintegration on firing. The forsterite bond in this brick has been very highly developed, as will be observed in the large area in photomicrograph Fig. 11. It is remarkable that this should be the case in view of the comparative purity of the chrome grains, but a probable explanation is that the gangue in this case was actually attached to the exterior of the grains themselves, and thus readily accessible to the periclase at the temperature of formation of forsterite.

The behaviour of these bricks in service was not too convincing, although it must be agreed that bricks S and R gave slightly better results than the brick marked C. It would appear that brick R gave about 10% better life than brick S, but the operating conditions were not entirely comparable. More recent tests do, however, indicate that the brick R will prove superior on a more prolonged trial.

Brick C failed prematurely, giving a life of 25% less than brick R. As far as could be ascertained, the operating conditions of these two trials were similar.

Conclusions

It would appear that the durability of this type of refractory depends on :—

1. The control of the chrome/magnesite ratio.
2. The composition of the gangue.
3. The respective grading of the chromite and magnesite fractions.

The last mentioned factor is of supreme importance. The failure of these bricks in furnace ports has often been traced to the presence of fine chromite grains in the original bricks. The removal of the chromite fines will, of course, tend to increase the cost of manufacturing chrome-magnesite bricks, unless a by-product value can be found for this material. Many firms are now producing a high grade chrome brick from these fine fractions, thereby permitting the maintenance of quality at an economic level.

The conditions of service are also of fundamenta importance. A consideration of the earlier remarks will visualise the adverse effect of alternate oxidising and reducing conditions. There is every indication that incorrect combustion conditions seriously affect the
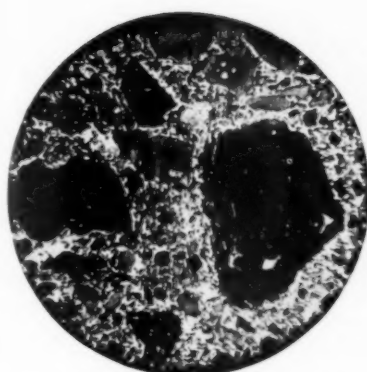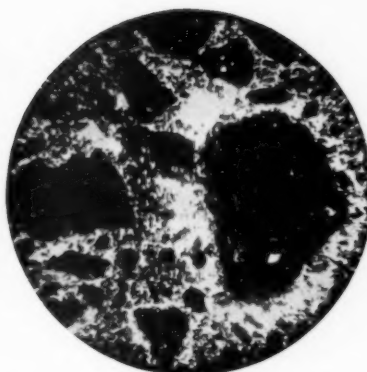
Fig. 6.—Brick S—ordinary light.   Fig. 7.—Brick—S—plane polarized light.   Fig 8. Brick C—ordinary light.
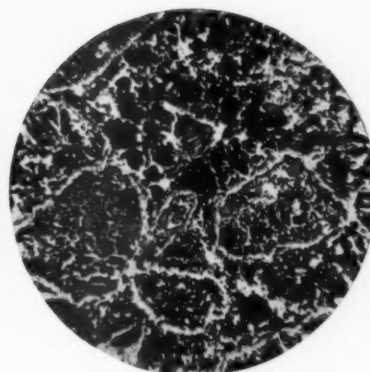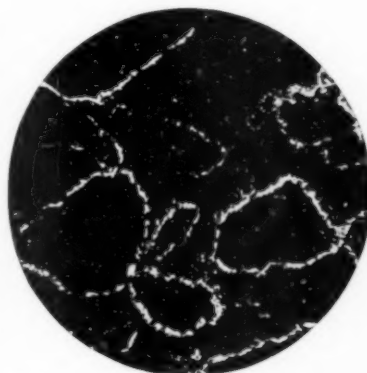
Fig. 9.—Brick C—plane polarized light.   Fig. 10.—Brick R—ordinary light.   Fig. 11.—Brick R—plane polarized light.

These micrographs were taken at a magnification of ×25 and reduced ½ linear in reproduction.

behaviour of these bricks in open hearth furnace port construction. Incomplete combustion appears to aggravate the growth of basic bricks in the port.

Although it is probably too early to be dogmatic, some recent work indicates that the difficulties with the refractoriness-under-load is being overcome. Providing the best quality of raw materials are used and the chrome-magnesite is hard fired, bricks can be produced to give a maintained under-load test equivalent to that of silica bricks, with even a superior final fail temperature in a rising temperature test. These results demonstrate the considerable advance which has been made in the manufacture of chrome-magnesite bricks in this country, many grades of which, in the author's opinion, are equivalent, if not superior, to the original Austrian brick.

Applications

Chrome-magnesite bricks have proved very successful in the back and front walls of basic open hearth furnaces and have had a limited application in the side walls of electric arc furnaces. In the non-ferrous field they have been successfully applied to copper refining furnaces, whilst in some cases the hearth troubles of re-heating furnaces have been overcome by the employment of this type of brick. At many steel plants this type of refractory is used exclusively for the construction of basic open hearth furnace ports, a practice which has

resulted in increased furnace life and a higher rate of production.

For many years the " All-basic " furnace has been the dream of steelmakers, but this type of furnace is still in the experimental stage in this country and America, although several interesting and encouraging progress reports have appeared in the technical press. It would appear that it offers an increased rate of output with lower refractory consumption, but the overall economics have still to be assessed in actual practice.

When using this type of brick in the roof, the general construction of the roof must be altered, due to the difference in the properties between basic bricks and silica bricks. It is impossible to employ a sprung roof, and some form of suspended roof must be adopted. This change of practice is necessitated because :—

1. The weight of the brick is much greater than in the case of silica.
2. At the temperature of operation, the crushing strength is much less than that of silica bricks.
3. The continual expansion and contraction during the different phases of the process, which is very different from silica, presents new problems.

These difficulties are overcome by replacing the conventional sprung arch by a completely suspended roof.

One weakness in the employment of a " basic " roof appears to be the cooling down during the charging period in the " cold pig and scrap " process and the

lower temperatures pertaining during the fettling period. It is, therefore, probable that the future design of open hearth furnaces will incorporate basic ends, front and back wall construction with a silica roof. The development of a higher grade of silica brick employing imported African quartzite may be of great future importance.

Copper and Copper Alloys
A Survey of Technical Progress during 1951

By E. Voce, Ph.D., M.Sc., F.I.M.

Copper Development Association

Continued progress has been made during the past year in the metallurgy of copper and its alloys, and in the various sections of this review the author discusses the principal items of interest concerning such subjects as raw material resources, extraction, fabrication, finishing and properties.

Plating and Finishing

Electrodeposition of Copper. It is claimed in a British patent[86] that improved bright deposits can be obtained from the acid sulphate bath by the addition of certain metallic salts in conjunction with such normal brightening agents as thio-urea. The metals cadmium, zinc, cobalt and nickel all have somewhat similar effects. For instance, cadmium sulphate in amounts up to 75 gm. per litre enhances the brightening effect of thio-urea, and improves the deposit in respect of softness and texture.

Sofranek, Combs and Faust[87] maintain that ductile, mirror-bright deposits of copper can also be obtained from acid sulphate baths by the addition of organic compounds such as the sodium salt of sulphonated di-para-toluyl sulphide, sulphonated di-para-toluyl disulphide and sulphonated di-para-toluyl sulphoxide. The use of such a deposit as an undercoat for bright nickel plating obviates intermediate polishing, while the copper deposit, as such, is attractive as a decorative finish, especially on plastics.

In reply to an enquiry concerning the electrodeposition of copper on stainless steel, Diggin[88] states that cathodic pre-treating in 5–50% sulphuric acid at room temperature has been successfully used. This is followed by a strike from a dilute acid copper sulphate bath, and then by plating from a similar but more concentrated bath. To supplement this information, Head[89] emphasises the need for careful preparation of the surface, especially in respect of the complete removal of oxide scale, and describes in detail a number of suitable plating baths.

A recent development in connection with the electrodeposition of copper from pyrophosphate solutions is the addition of nitrates to the bath,[90] thus doubling the rate of deposition and producing more ductile coatings. Apparently such coatings can be applied directly to stainless steel and aluminium, for it is claimed that, on these materials, they have covering power and adhesion superior to those produced from any other type of bath.

Papers by Jernstedt[91, 92] have emphasised the advantages obtainable with the periodic reverse current technique. The process is particularly applicable to the deposition of thick, dense coatings of copper from cyanide solutions at reduced costs.

Ultrasonic vibrations are finding increasing applications in many technological fields, and Roll[93] has studied their effect on the electrodeposition of copper and zinc. Such vibrations are said to improve efficiency, but it seems doubtful whether the advantages to be gained would justify the necessary equipment in commercial practice.

As interest is being taken in this country in the electrolytic production of thin copper sheet, some data on the strength and ductility of such material recently published by Prater and Read[94] should prove of value. The range of thicknesses investigated was from 0·00066–0·0036 in.

Electrodeposition of Copper Alloys. To those who have been concerned with the electrodeposition of speculum metal as developed by the Tin Research Institute, it may be of interest to learn that a similar process is under investigation in Russia.[95] Though not identical with the British solution, that proposed contains substantially the same chemicals. Parallel work is also in progress in India[96] where it is claimed that the addition of hydrogen peroxide to the bath improves the deposit.

Ferguson, Hovey[97] and co-workers[98] have reported an extensive investigation of the electrodeposition of copper-lead alloys for bearing purposes. Of a number of solutions tried they found one based on a mixture of cyanides and tartrates to be the most promising.

Electroforming. It appears that electroforming is now being used to an increasing extent, particularly in America, in numerous industries.[99] The process is particularly recommended for the production of tubular and cup-like shapes, especially those with re-entrant curves and angles, and for all purposes where accuracy of dimensions and the faithful reproduction of minute

surface detail are essential. For copper, an orthodox acid sulphate solution is used, and the tensile strength of the deposit ranges from 13–30 tons/sq. in., with hardnesses between 30 and 120 diamond pyramid numbers. If these figures are reliable, it means that copper can be obtained by electrodeposition with tensile strength and hardness values otherwise achievable only by the most severe cold working operations.

Electrolytic Polishing. While Jacquet,[100] the originator of electrolytic polishing, has published a general review of the orthodox processes, several innovations applicable to copper and copper alloys have been described.

Both copper and brass can, it appears, be polished anodically in solutions containing up to 12 gm. mol. of potassium cyanide per litre,[101] while the possibilities of using hexafluorophosphoric acid for the electrolytic polishing of brass and nickel silver on an industrial scale have been investigated by Martin and Young.[102] Fair results were obtained with brass, and those with nickel silver were even more encouraging. At the time that the experiments were undertaken, some three years ago, the acid was only available in relatively small quantities.

In America the idea has been patented[103] of wiping the surface of an article, mechanically, while it is being electrolytically polished. It is claimed that the wiping dislodges bubbles and also removes the protective film from the high points on the surface, exposing them to preferential attack. A viscous electrolyte should be used.

A Spanish author[104] claims to have developed an electrolytic polishing bath which is applicable to almost all metals and alloys. It consists of sulphuric acid 25 gm. per litre, hydrofluoric acid 33 gm. per litre, boric acid 8·3 gm. per litre, chromic acid 372 gm. per litre, citric acid 12 gm. per litre, phthalic anhydride 4·3 gm. per litre, and phosphoric acid 328 gm. per litre. An operating temperature of 200° F. is the most suitable irrespective of the metal or alloy being polished, while current densities and times of treatment are varied to suit the material.

Pickling. The application of solutions of ferric sulphate to the pickling of copper and its alloys has been put forward from time to time. Recently Bary[105] has advocated the addition of sulphuric acid and chromic acid to ferric sulphate baths for producing bright surface finishes on nickel silver and brass, respectively. For the descaling of brass tubes in condensers and heat exchangers, hydrochloric acid, inhibited with weakly basic organic compounds such as quinoline, aniline and other amines, is recommended.[106]

Schimmel[107] has outlined a process for the recovery of copper from copper-plated steel scrap by the use of an ammoniacal electrolyte. Under suitable conditions the copper can be dissolved anodically and deposited cathodically from such an electrolyte.

Colouring. A useful review of the methods available for the colouring and bronzing of metal and alloys, including copper-base materials, has been published by Harris,[108] who gives operative details for a wide range of different techniques, while Tyvaert[109] has described four formulae for the production of artificial patina on bronzes of various compositions. Techniques for the colouring of beryllium copper appear in the paper by Richards[51] already mentioned. Thompson[110] discusses the artistic enamelling of copper among other metals, a subject on which little has hitherto appeared in the metallurgical literature.

Properties and Applications of Copper and Copper Alloys

Mechanical Properties of Copper. Three separate researches on the creep properties of copper have appeared recently. In one of these, by Benson, McKeown and Mends,[111] attention was focused on the creep properties and rate of softening of several cold worked high conductivity coppers with and without additions of silver, the primary object of the work being to assess their relative merits for the rotor windings of large turbo-alternators. Stresses set up in such windings by thermal expansion and contraction may, under adverse conditions, lead to fracture of the copper, and a detailed analysis of the problem suggests that the most suitable grades of copper for the purpose are those which creep least and which best retain their work-hardness at the temperatures encountered. Comparative creep and softening tests on cold-worked tough pitch and O.F.H.C. coppers, showed the latter to be the better from both points of view. The addition of 0·08% of silver further improved the resistance to softening and creep, especially in the case of the tough pitch material.

Of the other two series of experiments on the creep of copper, one, by Jenkins and Digges,[112] was confined to O.F.H.C. copper while the other, by Blank and Burghoff,[113] dealt with phosphorus deoxidized material. Though both were concerned less directly with the technological application of the results obtained than was the work just described, yet each provides useful data for design purposes.

Though, in the light of the researches outlined above, together with others mentioned in previous Reviews, it can now be said that the slow extension of copper under creep conditions has been investigated with a fair degree of thoroughness, comparatively little information is available on its tensile properties under dynamic conditions of loading. However, work by Clark and Wood[114] has shown that the tensile strength of copper, in common with that of a number of other metals and alloys is increased by as much as 30% when the velocity of the test reaches about 25 ft./second.

Conductivity Materials. Recently Pawlek and Jahn[115] have reported a fresh investigation, using powder metallurgy methods, of the effects of various impurities on the electrical conductivity of copper. A summary of their results is given below.

EFFECT OF IMPURITIES ON THE ELECTRICAL CONDUCTIVITY OF COPPER
(Pawlek and Jahn)
Conductivities in Per Cent. I.A.C.S.

Element %	Oxygen	Nickel	Antimony	Arsenic	Silicon	Iron	Phosphorus
0·00	101·9	101·9	101·9	101·9	101·9	101·9	101·9
0·01	101·8	99·1	98·6	97·0	96·6	94·6	95·8
0·02	101·7	98·0	96·9	93·8	92·5	90·2	89·4
0·03	101·6	96·9	95·4	91·0	89·1	85·9	83·0
0·04	101·5	96·2	94·0	88·4	85·9	81·9	76·5
0·05	101·4	95·7	93·1	85·9	82·7	77·6	—
0·06	101·2	95·3	92·2	83·5	80·0	—	—
0·07	100·8	95·0	91·5	81·0	—	—	—

Details have been released of wires consisting of copper with 1·0–1·5% of nickel plus phosphorus in the ratio of five parts of nickel to one of phosphorus.[116] This alloy can be precipitation hardened, in which condition it has good spring properties combined with an electrical conductivity of between 55 and 60% I.A.C.S.

In earlier years, attention has been directed to the development of heat-treatable high-strength alloys,

consisting essentially of copper and silver, for conductivity purposes. A review of the latest practice in this field has been published by Pearson[117] while Margolin and Hibbard[118] have investigated the effect of adding third elements to the basic 5% silver alloy. Several of the added elements, notably phosphorus and magnesium, considerably enhanced the response of the alloy to heat treatment.

Bearing Alloys. Another direction in which copper alloys containing silver are being used is for bearings, and ternary compositions containing cadmium as the third element have been developed for this purpose.[119] For a considerable time phosphor bronzes containing tellurium to improve the machinability have been in use for bearings and bushes, and patents[120, 121] covering such materials have now been reported.

Alloys of Copper and Iron. The mechanical and other properties of the full range of copper-iron alloys have been studied by Smith and Palmer.[122] The alloys containing between about 5 and 10% of iron were found to have the highest strengths and were the most susceptible to improvement by age-hardening treatment. While the mechanical properties appear attractive, they are offset by lack of resistance to corrosion.

It appears that in Germany much of the open-hearth steel now produced is made from copper-bearing scrap. Because of this, Eisenkolb[123] has examined the effects of copper in amounts up to 1·2% on the deep-drawing characteristics, ageing and weldability of steels. It seems that regulations at present in force restrict the amount of copper to 0·5% for normal purposes and to 0·3% for deep-drawing operations. As a result of his experiments Eisenkolb recommends that these restrictions be retained.

Copper-Nickel-Antimony Alloys. Though antimony is rarely a constituent of copper-base alloys, Shibata[124, 125, 126] has carried out an investigation of the copper-nickel-antimony system. Much of the work constitutes an examination of the equilibrium diagram but, on the more practical side, the author found that the addition of antimony improved the resistance of certain cupro-nickels to the strong mineral acids.

Composite Metals. The production of various clad metals has recently been described by Siegel[127] who refers particularly to the coating of such materials as copper, brass, Monel and steel with silver and silver alloys, while a note[128] on the use of steel clad with copper emphasises its value as a shield for electronic communication equipment. Copper-clad aluminium is available commercially in the United States in the form of sheet and tubing[129] and can be used to advantage in the electrical field for such purposes as clips, shims, bushings and terminals.

Joining

Inert Gas Shielded Welding. Several papers on the application of the inert gas-shielded arc technique to the welding of copper and copper alloys have appeared. Conway[130] states that helium has proved superior to argon for the purpose, but Berryman[131] maintains that both gases have their advantages and disadvantages, and that mixtures of the two are desirable in certain cases. Robinson and Ferryman[132] have described tests on copper alloys using argon, and report that high-quality deposits of excellent appearance were made with several grades of aluminium bronze, silicon bronze and deoxidized copper filler rods. Phosphor bronze, with and

without lead, could be deposited, though some pinhole porosity was developed. The copper-zinc alloys were found to be difficult to deposit, but satisfactory welds could be made on brasses by using aluminium bronze filler rods.

Brazing, Soldering and Welding. Both Reebel[133] and Rose[134] have described techniques for the copper brazing of steels employing suitably compounded pastes instead of the more orthodox method of placing copper foil between the surfaces to be joined. They report substantial economies in respect of labour and material, as well as better flow of copper into tight press or rivet fits.

Richards[135] has outlined procedures for the brazing and soldering of beryllium copper, with special reference to the effects of the joining temperature on the properties of the material, while Boyden[136] has given particulars of an ingenious gun for brazing and soldering. The unit will feed brazing or soldering wire to the work either continuously or intermittently as desired, and once set in operation is almost automatic in performance.

A useful review of welding electrodes and rods for ferrous and non-ferrous metals including copper-base alloys has been published by Clauser,[137] while patents [138, 139] have appeared covering apparatus for making joints by the modern technique of "cold welding," whereby carefully cleaned metals, particularly copper and aluminium, can be joined under sufficient pressure to cause distortion without the application of heat.

Joints to Rubber and Glass. Brass has long been recognised to give excellent bonds with rubber, and when other metals are to be joined to rubber it is customary first to coat them with brass. With the advent of synthetic rubber the position has not been materially changed, and Kaercher and Blum[140] have found that the butyl type of synthetic rubber yields excellent bonds with brasses containing 70% of copper, provided that the surface is suitably prepared by rough polishing, degreasing and pickling.

A patent has been taken out for the production of glass-to-copper seals by coating the copper with a mixture of ground glass and a copper salt or oxide. On heating, this forms a thin vitreous film to which the glass is subsequently fused.[141]

Oxidation and Corrosion

Oxidation of Copper at Elevated Temperatures. Three valuable contributions to this important subject have recently been published by Tylecote[142, 143, 144] as a result of work at the British Non-Ferrous Metals Research Association. The first of these[142] comprises an able review of the literature, while the second and third record original investigations, respectively, of the rate of oxidation in air at temperatures between 350° and 900° C.[143] and the adherence of oxide scales to various grades of copper.[144] Tylecote found that the presence or absence of oxygen or phosphorus in the copper made no appreciable difference to the rate of oxidation at temperatures between 600° and 900° C., but below 600° C. the presence of phosphorus reduced the oxidation rate. The effect of phosphorus on the adherence of the scale was, however, much more marked. Scales formed on high-purity, oxygen-free and tough pitch coppers at temperatures from 400°–600° C. were substantially non-adherent, but at temperatures above 700° C. they became strongly adherent and would withstand a large amount of deformation without exfoliation

while sufficiently hot. Scales on coppers containing phosphorus were also non-adherent when formed at temperatures up to 600° C., while those formed at higher temperatures became sufficiently brittle on cooling to exfoliate readily. Arsenical coppers were intermediate in behaviour between these two types.

Aqueous Corrosion. Practical experience with the use of copper piping for sea water in ships has led MacMillan and Sharp[145] to instigate trials of cupro-nickel, Monel and rubber-lined piping. Though not immune from corrosion in such applications, copper piping is often held to represent a satisfactory compromise between life and economy of cost. Gilbert and May[146] have reviewed the available materials for use in ships' condensers and other sea water-carrying systems, paying considerable attention to alloys based on copper, while Bünger[147] suggests that stress corrosion and dezincification of condenser tubes carrying condensate contaminated with ammonia and oxygen, or polluted river water of high chloride content, can best be avoided by the use of 70 : 30 brass, with or without 1·0% of tin, with a recrystallised but not too coarse structure. On the other hand, Splittgerber[148] reports that, in the presence of oxygen, less than 1 mg. per litre of ammonia has a solvent action on brass condenser tubes.

Whitaker[149] states that copper tubing can be used for hydrofluoric acid, provided that the velocity of the liquid through the pipes is kept moderate. With fluorine, no serious corrosion occurs and, for laboratory work, copper tubing and brass compression fittings last indefinitely. Myers and Delong[150] confirm that copper also ranks among the few materials with good resistance to anhydrous hydrofluoric acid gas at temperatures up to 600° C.

Of wide general interest are a paper by Johnson and Bradbury[151] covering broadly corrosion resistant materials, both non-ferrous and ferrous, and a publication by the American Brass Co.[152] which includes a detailed chart giving the relative corrosion resistance ratings of copper and the chief copper alloys to 200 chemical compounds and solutions.

Atmospheric Corrosion. A lengthy and detailed report[153] covering the corrosion of overhead electrical equipment on steam-operated railways indicates that copper alloys, especially those of high copper content, were among the most resistant to this type of environment, being much superior to materials based on aluminium or iron. In general, the simpler copper-base alloys were preferable to the more complex, and wrought materials showed more resistance to smoke corrosion than cast samples of similar analysis. Copper-nickel alloys were satisfactory, while tin up to 10% and zinc up to 20% had little effect on the resistance to corrosion. Brasses containing higher percentages of zinc, as well as aluminium bronzes and aluminium brasses proved to be distinctly inferior to other copper-base materials. Copper-clad steels gave excellent service where smoke conditions were not severe.

Protection Against Corrosion. In recent years, publicity has been given to corrosion inhibitors for use in the packing of metals. These are essentially organic compounds which slowly sublime, and surround any article in an enclosed space with protective vapour.[154] While private information suggests that inhibitors of this type are more effective with ferrous materials than with copper-base alloys, experiments have been recorded[155]

indicating that satisfactory results were obtained with brass and copper among a number of other materials. On the other hand, the inadequacy of merely wrapping in cellophane as a protection against attack by traces of vaporised organic acid has been demonstrated by Simmons,[156] in the case of nickel silver.

In the light of a study of the corrosion of copper in a number of different salt solutions, Katz[157] recommends the addition of small amounts of alkaline buffers, such as lime or magnesium hydroxide, to salt solutions which have to be stored in copper containers. .

Physical Metallurgy

The Mechanism of Fatigue. A particularly thoughtful and illuminating paper[158] on the mechanism of fatigue in metals has reached this country from Australia. By X-ray assessment of the degree of "disorientation" of the crystal structure of copper after fatigue tests at various speeds and stresses, it was demonstrated that there is a definite time lag between the application of stress and the occurrence of the consequent strain. If, under fatigue conditions, the stresses are reversed more rapidly than a certain critical speed, very much less disorientation of the material occurs than if the same stress cycles are applied slowly. In spite of the apparent absence of disorganisation within the grains under rapid stress reversals, however, work hardening occurs, and may eventually lead to failure, which will then be of the brittle rather than of the ductile type. For the annealed copper used in the experiments, the critical speed was found to lie between 300 and 400 stress cycles per minute, and the variation of this critical rate with the magnitude of the applied stress up to the maximum investigated, namely ± 7 tons/sq. in., was negligible.

Stress-Ageing. Gill, Smith and Harrington[159] claim that by heating a metal to a moderate temperature, well below the recrystallisation temperature, while it is subjected to an externally applied load, marked improvements can be effected in certain mechanical properties, and frequently in the electrical conductivity. Data are given in the paper for a number of copper-base alloys, but it is sufficient here to quote a single illustrative example, namely that of a typical phosphor bronze cold worked to a 60% reduction of section. The properties of this material before and after heating for four hours at 175° C. under a stress of 33·5 tons/sq. in. were found to be as follows :—

	Before Stress-ageing	After Stress-ageing
Limit of proportionality, tons/sq. in. ..	17·6	33·6
Proof stress, 0·2% extension, tons/sq. in.	38·6	38·4
Tensile strength, tons/sq. in.	39·1	38·8
Elongation, %	14	17
Reduction of area, %	76	76
Electrical conductivity, % I.A.C.S. ..	16	21

It will be seen from these figures that the principal effect of stress-ageing is to raise the limit of proportionality to a stress approximately equal to that applied during the stress-ageing treatment. In certain cases, however, particularly with ferrous materials, limits of proportionality appreciably above the applied ageing stress were obtained.

Valuable though the process appears to be, its practical possibilities in connection with the manufacture of springs, diaphragms, bellows and similar appliances have yet to be established.

Plastic Deformation. Earlier in this Review, criticism was levelled at a paper by Arbel[65] on the grounds that he adopted the parabolic stress-strain equation which was at variance with his experimental data. Though this type of equation is widely accepted in America as representing the relationship between stress and strain for metals, in spite of its lack of universal applicability, it is encouraging to find that at least one prominent American authority, namely Geil,[160] has recently questioned its validity. Moreover McAdam,[161] in extending the stress-strain relationship for copper to embrace the effects of temperature, has judiciously refrained from any attempt to fit equations to his curves.

Unfortunately an attempt by Tabor[162] theoretically to correlate tensile with hardness tests is based on the same questionable parabolic relationship between stress and strain, and even this seems to have been applied to orthodox engineering strain, or percentage elongation, whereas it is properly confined to true, or logarithmic, strain alone. A more direct approach to the correlation of hardness with tensile strength has been made by Boklen[163] who adopts empirical conversion factors and quotes 180 examples from published literature, including some relating to copper.

From experiments on the plastic deformation of copper when drawn through a conical die, Navarro[61] concludes that the most severe practicable reductions have the advantage of ensuring uniformity of cold work across the sectional area and of minimising the risk of internal necking.

Recovery and Recrystallisation of Copper. In recent years the mechanism of recovery and recrystallisation of cold-worked copper has received considerable attention. In most of this earlier work, the extent of recrystallisation was assessed from the mechanical properties, usually hardness, of the material. A somewhat different approach has been made by Lucke[164] who measured the progressive alteration in the electrical resistance of cold-worked copper after annealing for various periods at 120°, 140° and 180° C., while Backofen[165] studied the deformation and recrystallisation textures of heavily cold-drawn O.F.H.C. copper when annealed at temperatures between 300° and 450° F. The results of both these investigations were in substantial conformity with those obtained by previous workers.

Diffusion of Metals in Copper. The rates of diffusion of zinc, cadmium and silver in copper have been determined by Kubaschewski[166] at temperatures between 710° and 860° C., and the literature concerning rates of diffusion in a number of other alloy systems was reviewed. It is concluded by the author that most of the published information calls for careful redetermination.

Thermal Expansion of Copper. As the result of tests on copper of high purity, Epplesheimer and Penman[167] confirm that the thermal expansion is a smooth function of temperature throughout the range from 18°–770° C.

Friction of Metals. Simon, McMahon and Bowen[168] have determined the coefficients of dry static friction of copper among other metals at temperatures ranging from near the absolute zero to upwards of 300° C. Shear strengths and hardness values were determined over the same range of temperature, and it was found that, in spite of a large variation in both these properties with temperature, the ratio between them closely followed the change of the static friction coefficient with temperature. It is claimed that this fact substantiates the adhesion theory of friction.

Powder Metallurgy

Production of Copper Powder. Three useful papers relating to the electrolytic production of copper powder have appeared. The first of these, by Wranglen[169] touches upon an aspect of the subject which seems to have been somewhat neglected, namely cathodic deposition by the electrolysis of fused salts. The remaining two, by Mehl[170] and Drumiler, Moulton and Putnam[171] respectively, deal with electrodeposition from aqueous solutions of copper, mainly sulphates.

A British Patent[172] has appeared covering the production of metallic powders by atomising a stream of molten metal by means of an annular air jet in the presence of hydrogen.

Pressing and Sintering. A comprehensive study of the effect of oxide on the pressing and sintering of electrolytic copper powder has been published by Hoar and Butler.[173] It is evident from this work that the effect of oxide is by no means simple and depends to a large extent, as might be expected, on the atmosphere used during the sintering process. In hydrogen, for instance, it is shown that oxide reduction is complete after treatment of a porous compact at 435° C. or above for four hours, and that in argon or nitrogen, oxide vaporises from the outer layers of compacts heated to 755° C. or more. The specimens lost weight and sublimed cuprous oxide was found in the cooler parts of the system. Jordan and Duwez[174] have also investigated the effect of pre-reduction with hydrogen on the sintering of copper compacts.

A novel process for the production of sintered compacts in aluminium bronze has been patented by Primavesi.[175] Copper and aluminium powders in the desired proportions are ball-milled with a small quantity of a powdered metal, such as titanium, molybdenum or lithium, which is capable of taking up hydrogen at a temperature below that of sintering. Compacts of such mixtures are heated in hydrogen at a relatively low temperature and on subsequently reaching the sintering temperature the hydride so formed decomposes to liberate hydrogen.

Production of Strip from Metallic Powder. A recent development is the continuous production of metallic strip by cold rolling the appropriate powders.[176, 177] The method has already been applied to bronze as well as to iron, but its possibilities have not yet been fully explored. While the cost of metallic powders remains as high as at present, the process would appear to be without advantage over the more orthodox methods of strip production, but it might well be applied in certain limited directions, especially if it is found that the degree of porosity in the resultant strip can be controlled. Moreover, there would appear to be possibilities of incorporating non-metallic additions in the rolled strip if desired, or of producing strip from metals not readily rolled from ingots.

Antifriction Materials. Two notes by Bowden[178, 179] have outlined the production of materials with excellent bearing properties by the use of porous copper compacts impregnated with non-metallic materials. One of these is a fluorine-containing plastic, which, on a matrix of porous copper, gives remarkably low coefficients of friction of the order of 0·05. It can be used at temperatures up to at least 300° C. without breakdown. A second proposal is to use molybdenum sulphide as a surface layer on sintered copper or molybdenum. This com-

pound has a lamellar structure with low coefficient of friction, which is retained at temperatures up to 400° C.

The sintering characteristics of mixed copper and graphite powders for antifriction and electrical purposes have been studied by Heuberger,[180] while Greenwood[181] has published an up-to-date review of impregnated and infiltrated alloys.

Analysis and Testing

Electrolytic Determination of Copper. In analytical laboratories controlling the production of copper and copper alloys the electrolytic method of determining copper is almost universally employed. An able review of the techniques which have been used in the past with an account of modern practice has lately been published by Skrowronski,[182] who covers the subject in considerable detail. As the electrolytic analysis of arsenical copper presents a certain amount of practical difficulty, a paper on the subject by Norwitz[183] should prove of value. He proposes an electrolyte containing nitric acid and ammonium nitrate, claiming that from 0·1–0·5 gm. of copper can be quantitatively separated from a similar amount of arsenic as well as from small concentrations of antimony and tin.

Automatic Spectrographic Analysis. The automatic spectrographic analysis of copper and copper alloys by means of the " Quantometer " has, according to Haser, Barley and Boyd,[184] been developed with marked success. The authors give details of four different types of discharge, each of which is suited to a special class of problems encountered in copper alloy analysis.

Identification of Metals and Alloys. A new non-destructive technique of distinguishing between various metals and alloys is based on the electropotential developed between the material under examination and a suitable electrolyte.[185] The procedure is simple and merely involves noting the deflection of a millivolt meter when contact is made with the specimen through the electrolyte. It is claimed that up to 1,000 samples per hour can be tested under production conditions. It is by no means certain, however, that the apparatus would distinguish critically between different copper-base alloys.

Miscellaneous

Locomotive Fireboxes. In spite of a tendency in America and elsewhere to adopt steel firebox plates and stays, it is encouraging to note that copper has been specified for the inner firebox of the new British Standard locomotives[186] and also for certain locomotives for the South African railways.[187] In the latter case the wrapper plates and inner back plates, as well as the rigid firebox stays, are of copper in order to provide resistance to corrosive attack by the poor quality boiler water used.

The Use of Specifications. Both purchasers and suppliers of non-ferrous products, particularly in the form of sheet and strip, would do well to read a thoughtful article by Crow[188] on the subject of the use and abuse of specifications. Judiciously applied, a specification makes an invaluable servant, but by adherence to inappropriate specifications without due regard to the purposes to which the material is to be put, they may become intolerant masters.

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Hadfields Products Displayed

WHEN H.R.H. The Duke of Gloucester opened their new centralised forge, an arresting feature of the reception given by Messrs. Hadfields, Ltd., at their East Hecla Works was an exhibition of their various products.
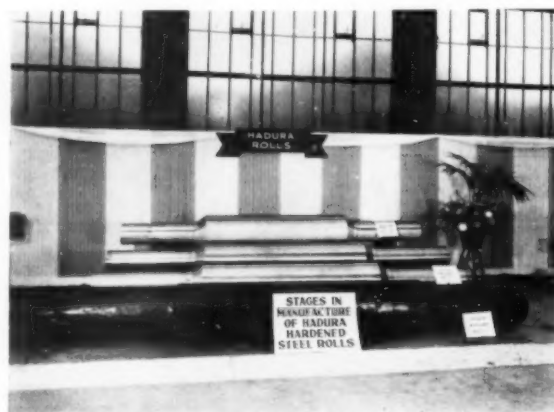
Two rows of stands, 100 yds. long, with a carpeted path between, had been laid out and erected in a bay of their No. 1 Machine Shop. Arranged in well assorted groups, the exhibits, all taken from work in progress, effectively displayed the variety and high quality of the steel components and the engineering work produced at their plant.

Included in the exhibition were steel buckets, tumblers, etc., for dredgers; wheel centres for locomotives; railway track; colliery equipment; crushing machinery; and rolled, forged and cast steel for many kinds of engineering uses. A comprehensive selection of forgings included parts for metal extrusion presses, a composite back-up roll, and "Hadura" work rolls for cold rolling strip and sheet. Precision castings were shown, with an interesting set of illustrations of manufacture by the lost-wax process.

Examples were to be seen of methods employed for the non-destructive testing of steel which are extensively used by Hadfields as a means of developing and maintaining high standards of manufacture, whilst another stand showed an interesting selection of articles produced by apprentices.

It is unlikely that a collection so impressive and so wide in scope has ever been on view representing the production of a single factory, and there is no doubt whatever that it was worthy of the distinguished occasion for which it was prepared.

Corrosion of Buried Metals
A Report of the Recent Symposium

The replacement costs of buried pipes in this country are estimated to be in the region of £50,000,000. This serious problem was discussed recently at a Symposium on the Corrosion of Buried Metals, organised by the Iron and Steel Institute in conjunction with the British Iron and Steel Research Association and the Corrosion Group of the Society of Chemical Industry. A brief report of the proceedings is presented here.

THE Symposium on the Corrosion of Buried Metals held by the Iron and Steel Institute in conjunction with the British Iron and Steel Research Association and the Corrosion Group of the Society of Chemical Industry, in London, on December 12th, 1951, with Sir Charles Goodeve, F.R.S., in the chair, was attended by 300 people.

Introductory Remarks

Opening the Symposium, Sir Charles said that all modern civilised communities were dependent on a number of services carried in the ground—water, gas, electricity and sewage being the chief. Of these, water mains presented the greatest corrosion problems ; some 100,000 miles were estimated to be under risk in this country in 1949, with another 25,000 miles of new mains under consideration.

Research on the corrosion of buried metals had lagged behind the advances in knowledge of methods of combating atmospheric corrosion, and the Report of the Ministry of Health Departmental Committee on the Deterioration of Cast Iron and Spun Iron Pipes, published in 1950, had stressed the need for further research. B.I.S.R.A.'s Sub-Committee on the Corrosion of Buried Metals had been formed in March, 1950 and was entrusted by the Minister of Health with the task of carrying out the research recommended in the Departmental Committee's report. The Sub-Committee included representation of all the interests concerned—gas, water, engineering, non-ferrous metals, pipe manufacturers, etc., under the Chairmanship of Mr. L. C. Whiskin, Distribution Engineer of the Metropolitan Water Board, and registered a very satisfactory degree of co-ordination of these interests.

One of the Sub-Committee's earliest actions had been to initiate the organisation of this symposium. There were to be six papers, constituting a general survey of existing knowledge on the subject :—

Tests on the Corrosion of Buried Iron and Steel Pipes. By J. C. Hudson and G. P. Acock.
Investigations on Underground Corrosion. By K. R. Butlin, W. H. J. Vernon and L. C. Whiskin.
Cathodic Protection. By K. A. Spencer.
Cathodic Protection of Buried Metal Structures. By R. de Brouwer.
Corrosion of Buried Copper and Ferrous Strip in Natural and Salted Soils. By the British Electrical and Allied Industries Research Association.
Tests on the Corrosion of Buried Aluminium, Copper and Lead. By P. T. Gilbert and F. C. Porter.

Discussion of these papers was to be taken in three sessions, each pair of papers being taken for discussion successively.

The first two and the last two papers were essentially the work of Research Associations or Laboratories (the Iron and Steel, the Electrical and Non-Ferrous Metals Research Associations and the Chemical Research Laboratory). In some of these researches valuable collaboration had been received from other organisations such as the Institution of Water Engineers and the Metropolitan Water Board. The other two papers were concerned with cathodic protection, a method which would undoubtedly be of very great importance in the future.

Tests on the Corrosion of Buried Iron and Steel Pipes

Dr. J. C. Hudson, Head of the Corrosion Laboratory of the British Iron and Steel Research Association, gave a brief survey of the events leading to the research described in the first paper, and Mr. Acock outlined the interim results contained therein. Three sets of steel and cast iron specimens, covering a wide range of bare and coated ferrous pipes, had been buried in four typical British soils in 1944, and a fifth set in made-up ground. The soils at the five sites were salt marsh, London clay, moist neutral clay, Keuper marl, and cinders, respectively. The first set from the four and the single set from the fifth station had been examined after five years' burial. For bare pipes, differences in the aggressiveness of the soil were more important than differences in the the material of the pipes. It appeared that differences that had been reported in the resistance to corrosion of spun and vertically-cast iron pipes had been due rather to differences in wall thickness than to any other factor, the former type of pipe being up to one-third thinner for equal mechanical properties.

While it was too early to draw firm conclusions from the behaviour of the various coatings, it might be observed that a zinc coating of 2 ounces per foot protected the specimens over the five years, except in ground made up of ashes, where corrosion was heavy. A $\frac{1}{4}$ in. thick bitumen coating on steel tube was almost perfect at this site, but a thin hot-dipped coal-tar-pitch coating, 5 mils. thick, on cast-iron pipe had failed. Protected specimens were removed from only one other site, in the Keuper Marl, where the bitumen coating was intact but the coal-tar-pitch coating showed signs of failure. Vitreous enamel on cast-iron was in perfect condition at this site, but a stoved phenolic-resin coating on steel had failed because of its thinness.

Investigations on Underground Corrosion

Dr. W. H. J. Vernon, O.B.E., Head of the Corrosion Group of the Chemical Research Laboratory (D.S.I.R.) introduced this paper the first part of which recapitulated the work carried out at the Chemical Research Labor-

Fig 1—Examples of corrosion by graphitization on cast iron pipe with standard coating, after three years burial at Chigwell

atory on sulphate-reducing bacteria from 1934 onwards, which confirmed the conclusions of Dutch investigators on the part played by *Vibrio desulphuricans* in causing anaerobic corrosion of iron and steel pipes in neutral, waterlogged soils.

Fundamental studies of the bacteria, their morphology, culture and inhibition were continuing, and progress had been made. For example, it had been discovered that selenates prevented sulphates from being reduced, and this might be applicable in protective coatings. Field investigations in collaboration with the Institution of Water Engineers showed that corrosion associated with sulphate-reducing bacteria was the most widespread and dangerous form of underground corrosion.

The second part of the paper described experiments on the protection of ferrous pipes at Chigwell made in collaboration with the Metropolitan Water Board. In similar conditions to those obtaining at Chigwell, microbiological corrosion had been known to occur within 12 months, and commonly within 10 years. Large-scale tests were, therefore, begun there, with various types of protection, when new mains were laid in 1945. Almost three years after laying, the main was examined. The portion protected with a standard 0·005 in. hot-dip coal tar enamel bath (the Angus Smith solution) was badly graphitised as shown in Fig. 1. Bitumen sheathing ⅜ in. thick, however, gave adequate protection, as did surrounds of good quality concrete or gravel. Further trials were now in progress at Chigwell and at Willesden.

Joint Discussion

Dr. W. F. Higgins (Magnesium Elektron, Ltd.) questioned the value of tests using short lengths of pipe.

The service pipe, passing through various soils, would corrode only in cases where it became anodic. It was significant that the specimens shown by Dr. Vernon, cut from long lengths of buried pipe, were much more severely corroded than Dr. Hudson's specimens which had been buried as short lengths. Dr. Hudson's specimens might give an indication of the behaviour of iron and steel when buried under the conditions he described, but would not afford an indication of the behaviour of pipelines. A most important remark in Mr. Acock's address was that it appeared that the nature of the ground was of greater consequence than the type of metal.

Mr. W. G. Waite (Cathodic Protection Division, F. A. Hughes & Co., Ltd.) supported Dr. Higgin's contention. Tests, he thought, should operate under the same conditions as those the average engineer had to face. In a length of pipeline, large concentration cells would often form, and only tests in a long trench could provide information of circumstances such as these. Another point was that long lengths of pipe were frequently not perfectly buried in the bottom of the trench, which resulted in differential aeration and sometimes penetration of the coating at points of bearing. He also considered that a point had been missed in not measuring the conductivity of the ambient electrolyte.

Mr. Waite felt that perhaps too much stress had recently been laid on the part played by bacteria in corrosion, and that more stress should be laid on the cell mechanism that led to it. Discussing the protective coatings tested at the Chemical Research Laboratory, he commented that a hot-dipped coating was permeable and would break down once rusting started, but it would remain useful for a long time if rust could be prevented

from starting. Bitumen was very vulnerable to damage by stones, and concrete surrounds lacked flexibility and raised the danger of concentration cells again. Gravel needed good and consistent drainage to be effective and, in fact, usually became choked. He expressed surprise that no attempt had been made to test cathodic protection at Chigwell.

THE CHAIRMAN commented that the problem of using large scale or small scale tests occurred in many branches of scientific work. Account must be taken of the fact that accuracy of measurement fell off as the scale of the work was increased from the small scientific test towards the test under practical conditions ; the cost also rose. There was frequently an optimum point where economy of effort, accuracy of measurement and correspondence to practical conditions most nearly coincided.

MR. N. J. PUGH (Corporation Water Undertaking, Coventry), speaking for the user of pipes, joined in the criticism of the tests on short lengths which, he said, could hardly indicate service conditions, nor could they indicate the internal stresses caused by the fluctuation of pressure, and he urged that tests should be carried out in close co-operation with the user. On the question of the economy of such tests, he had heard a figure of £5 million quoted for replacement costs of buried pipes, and he thought that £10 million would probably be nearer the mark. He thought that the academic causes of corrosion were less important than a study of the way to lay pipes so protected that corrosion would not occur.

DR. F. WORMWELL (Chemical Research Laboratory) described the work continuing at the C.R.L. in this direction. He said that many pipes submitted by water undertakings were examined and reported on, some undertakings using the standard form supplied for this purpose and some submitting their specimens independently. In this way the Laboratory maintained close touch with the engineers who were facing practical problems. Work in the Laboratory included electrochemical measurements which might throw light on the behaviour of bacteria.

MR. E. W. RAWLINGS (Semtex, Ltd.) commented on the protection which cement mixtures could afford. Latex cement, which could be sprayed on to pipes, had been successful when used in conjunction with hessian or glass cloth to reduce mechanical damage when laying or back filling.

MR. J. G. PARRY (Fibreglass, Ltd.) referred to the standards laid down and used by the Dutch. He thought that in this country much applied and practical work was not put into the hands of the engineer.

MR. F. E. WARNER (Carless, Capel & Leanard, Ltd.) reported his firm's experience with large underground structures such as storage tanks. These were used for storing petroleum and coal tar distillates and as a safeguard against outflow in case of perforation were surrounded with 6 inches of puddled clay. This had been the practice for at least 60 years and, in spite of the sites being waterlogged, tanks of this age or older were still in use, and were not corroded seriously on the outside when excavated. Of course, some of the really old tanks might be iron, not steel. Corrosion of the type shown had been found after about 15 years with the connecting pipelines buried in soil about 2 ft. down. It might be that these had become anodic and protected the tanks.

Author's Reply

Replying to the discussion, DR. VERNON said that the tests involving short lengths of pipe did not fail to take account of experiences with longer lengths in the field. Co-operation with actual users was an essential feature of the work, and every possible step had been taken to co-operate with water and gas engineers, as could be seen from the standard form which was being widely used to report corrosion failures of buried pipes. The figure of £10 million replacement costs given by Mr. Pugh was itself an underestimate, the latest estimate being in the neighbourhood of £50 million.

He agreed that there had been a tendency to over-emphasise the microbiological causes of corrosion, and he and his colleagues had taken every opportunity of pointing out that microbiological corrosion was not basically different from electrochemical corrosion, of which it was merely a special type. However, it should be pointed out that the very great majority of pipeline failures in this country had been associated with unmistakable symptoms of microbiological influences.

MR. L. C. WHISKIN (Metropolitan Water Board) said that the tests at Chigwell were carried out in one continuous trench, and the pipes were laid in accordance with normal main-laying practice. Cathodic protection was not included in the tests as five years ago this practice was not so well known and was, indeed, regarded with some suspicion. He admitted that now more information was available he wished that such protection had been installed.

He said that the Sub-Committee on the Corrosion of Buried Metals was now concentrating more on methods of prevention than on the causes of corrosion. In this connection, he emphasized, in the case of main-laying, the importance of taking every care in the transport and handling of pipes and in the back filling of trenches in order to avoid damage to coatings ; the Report of the Departmental Committee of the Ministry of Health on the Deterioration of Cast Iron and Spun Iron Pipes published in 1950 contained much useful information on the subject.

Cathodic Protection

MR. K. A. SPENCER, of the Anglo-Iranian Oil Co., Ltd., introduced both his own paper and that by MONSIEUR R. DE BROUWER, who was unfortunately prevented from attending. Mr. Spencer said that it was now generally appreciated that a properly designed cathodic protection installation would protect a buried steel structure indefinitely. Corrosion of a buried or submerged structure was generally the result of one or more of four causes :—

(a) the concentration-cell effect, occurring where changes in the concentration of soluble salts in the soil along the length of a pipe line would cause the areas of higher concentration to become anodic. This was the principal cause of pipe-line corrosion in the Middle East ;

(b) the electrolytic-cell effect caused by stray direct currents resulting in a variation in the potential of a buried pipe line relative to the soil ;

(c) the galvanic-cell effect, caused by contact between dissimilar metals ;

(d) the bacterial corrosion in anaerobic conditions, which was the chief cause of underground corrosion in the United Kingdom. Sulphate reducing bacteria accelerated corrosion from this cause by removing hydrogen on polarisation.

Whatever the cause, the corrosion of metals was

associated with a positive electrical current flow from the metal to the electrolyte at the anode—the point of corrosion. Cathodic protection was based on the simple conception that if sufficient electrical current were flowing uniformly into the metal surface from the electrolyte, the flow from the anode was stifled and corrosion did not take place. Cathodic protection could, therefore, be affected by providing a flow of current either from a higher potential scrap-metal groundbed anode supplied with an external direct current, or from expendable metal anodes such as magnesium, aluminium or zinc, having a higher electrode potential than steel. In this case current was produced as in a " dry-battery."

Mr. Spencer said that to ensure protection a current of between 1 and 15 mA./sq. ft. of exposed metal was usually necessary. Hence the need for good and continuous coatings, which were complementary to cathodic methods. The potential between metal and electrolyte had to be assessed, and this could conveniently be measured by a high resistance voltmeter with a copper/copper-sulphate half-cell. Natural potentials were usually from -0.35 to $-0.70V$. It had been found that if more than $-0.85V$. were maintained, by application of cathodic protection, full protection was provided.

It was also necessary to survey the soil before applying cathodic protection ; the most convenient method was to measure its electrical resistance. A broad designation was :—

Very corrosive ..	..	Less than 500 ohms/cc.
Corrosive	..	500–2,000 ohms/cc.
Mildly corrosive	..	2,500 ohms/cc.

Where soil resistivities were very high, the potential developed by sacrificial anodes was not sufficient and the power-supplied system had to be used.

Mr. Spencer briefly described sacrificial and power-supplied installations, and quoted examples where considerable economies had been effected. Cathodic protection was finding increasing application to oil, gas and water lines, tank bottoms, jetties, water tanks, ships' hulls, process plant and buried power-transmission lines.

Cathodic Protection of Buried Metal Structures

Mr. Spencer in introducing this paper, said the author was the Technical Manager of the Société de Distribution du Gaz, Brussels. The paper dealt with cathodic protection by " polarised drainage " and " forced drainage." Those methods had been extensively used on the Continent, where there were many tramways and railway lines using direct current, the presence of which complicated the practical installation of cathodic protection.

" Polarised drainage " consisted of the neutralisation of anodic areas caused by stray currents leaving the structure, by recourse to connecting the pipeline to the return circuits of the electrical traction lines from which the stray currents originated. The drainage apparatus had to be large enough to resist inverse potentials of the order of a score of volts or so, and to allow the flow of several hundreds of amperes without producing large potential drops.

" Forced drainage " was applied where the potential of the rail did not constitute a sufficient source of current and it was not necessary to insert in the electric circuit a supplementary source of E.M.F. Practical applications of both methods were described in both papers.

Joint Discussion

The subject of the measurement of soil potentials excited considerable comment in the discussion on these papers. DR. A. J. MAURIN (Gaz de France, Paris) distinguished between specific aggressivity and apparent aggressivity over the length of a pipeline. Nomograms had been constructed for calculating specific aggressivity from characteristics of the soil which could easily be measured. No main was laid in France to-day without both the specific and apparent aggressivity of the soil having been ascertained. Some 600 kilometres of new mains were being protected every year. They were also considering the use of ultrasonics to combat the sulphate reducing bacteria.

MR. J. H. GOSDEN (British Electricity Authority) also emphasised the value of measuring potential in assessing the danger of corrosion. This was important where power cables were concerned, as corrosion was often confined to areas where the conditions were particularly severe, as, for example, where they were subjected to stray currents from traction systems. Mr. Gosden gave details of potential measurement at a substation where corrosion of lead-covered and served cables had been caused both by stray currents from an adjacent traction system and by electrolytic action. The tests showed that the potential between the cable and the soil was the factor which controlled the rate of corrosion.

MR. W. WESTWOOD (British Cast Iron Research Association) raised a practical point in measuring potentials. He asked Mr. Spencer where he put the copper sulphate half-cell when he was carrying out his measurements. If it were put in the soil above the magnesium anode, it gave a greater reading than if it were placed vertically above the pipe, which in turn gave a greater reading than if it were placed in remote earth.

Mr. Westwood mentioned that one must not forget that there were very many miles of water pipes that did not corrode, nor was corrosion always the cause of failure. Ground movements sometimes caused failures, though subsequent corrosion might appear on a casual examination to have been the primary cause.

MR. J. R. WALTERS (General Post Office) commented that the necessary cathodic potential " drifted " with time due to polarisation, and the current required tended to become less.

MR. H. C. S. HAYES (General Post Office) said that the Post Office had some 35,000 miles of main trunk cable and, in 1950, about 1,000 sheath faults occurred on these due to corrosion, and 3,000 more on shorter cables. 45% of 6,000 exchange areas covering the country had been affected by corrosion at one time or another. Practically all the cables were bare lead in earthenware pipes, and only about 5% of the total cable mileage had a protective covering on the lead sheath. The series resistance of the lead sheath per mile for bare cable in earthenware ducts was about one half to five ohms, depending on the cable size, and the resistance to earth depended upon the wetness of the ducts, but normally was of about the same order. When hessian tape and compound-covering was used over the lead, as was sometimes done in areas subject to corrosion (other than in areas where there were tramways), the insulation to earth, although comparatively low, of the order of from two ohms to one hundred ohms per mile, was sufficient to provide the Post Office with complete protection, and

there had only been one or two cases of failure, and these were where the protection had been damaged mechanically. This was a relatively expensive method, however, and it was thought that cathodic protection might cut costs. Cathodic protection had been tried in seven exchange areas, one of them in Lavington in Wiltshire where, since connecting it up in 1946, no faults had occurred. Previously, for some years, sheath faults had averaged two per year. The other six cases were not so conclusive but did encourage further investigation.

Another installation of cathodic protection was commented on by MR. C. W. MARSHALL (British Electricity Authority) who expressed admiration of the way the Belgians had made a large number of commercial installations "instead of only writing reports." An example of the way they used the most economic methods available was between the Schelle Power Station and Antwerp where 16 kilometres of power cable, operating at 70,000 volts, passed through very aggressive soil. Since 1938 complete immunity from corrosion failure had been achieved by the use of cathodic protection.

MR. C. W. N. McGOWAN (Kuwait Oil Co., Ltd.) described a cathodic protection installation on jetty piling in the Persian Gulf.

MR. J. FERDINAND KAYSER (Gillette Industries, Ltd.) said that cathodic protection was applicable not only to buried metals but to parts of prime movers, chemical plant, fine instruments and the like. It was possible that on occasion parts of a machine or instrument might be fortuitously in a state of cathodic protection ; a safety razor holder made from aluminium did, for instance, protect the razor edge from visible corrosion, but such protection apparently tended to alter the physical properties of the metal in the vicinity of the edge. Cathodic protection could be used completely to protect the edge from rust, but if one unduly increased the protecting current, the edge would then wear away at a rate roughly proportional to the current density. He could not envisage cathodic corrosion of steel and would like to ask if either of the authors had found any evidence that the physical properties of cathodically protected metals were adversely affected. He thought this was important, because in a seaplane a ferrous part might be fortuitously cathodically protected and show no signs of rust, yet its physical properties might deteriorate to such an extent that failure might occur.

DR. VERNON said that the alkali deposit might play a part in precipitating protective deposits. This might be what happened at the razor's edge, though he thought it dangerous to extrapolate from there to a buried pipeline !

Authors' Reply

Replying to the discussion MR. SPENCER said that he thought that Mr. Marshall underrated the extent of work completed in this country and the Middle East. There was a considerable amount of work on cathodic protection going on. So many variables entered into the planning of protection schemes that trial and error was a necessary procedure in many cases. Replying to Mr. Westwood's question about the half-cell he said that he advocated placing it as near the pipe as possible. In connection with Mr. Walter's point of reducing the potential, he thought that the saving was so small, in relation to the capital cost, that it was scarcely worth considering.

Corrosion of Buried Copper and Ferrous Strip in Natural and Salted Soils

This paper, contributed by the British Electrical and Allied Industries Research Association, was introduced by DR. G. MOLE. It described an investigation to determine the relative corrodibility in different soils of metals used for earth electrodes. Over a period of 12 years the behaviour of cast iron, Armco iron, mild steel, galvanised mild steel, copper and tinned-copper in 12 soils was investigated. As the soil surrounding electrodes is often salted as an anti-corrosion precaution, salted and unsalted soils were used at each site.

It was found that tinned copper was the most corrosion resistant, usually losing by corrosion less than 0·1% per year, compared with nearly 2% for unprotected ferrous specimens. Galvanising, however, gave mild steel considerable protection, which lasted at least 12 years. Salting generally increased the corrosivity of the soils.

Tests on the Corrosion of Buried Aluminium, Copper and Lead

In introducing this paper, MR. F. C. PORTER described tests on tubes of commercial-purity aluminium, phosphorus-deoxidised arsenical copper, and lead, buried at the same time and on the same sites as the ferrous specimens referred to in the first paper. As iron and steel pipes were most commonly used for mains and non-ferrous metal pipes for supply lines, the two investigations were deliberately undertaken in parallel. The aluminium was severely pitted after 5 years in all soils except the moist neutral clay, where there was virtually no attack. Cinders caused severe attack on copper, and in the other four soils the attack varied from practically nothing to a moderate localised attack, up to about 0·2 mm. deep (about 10% of the wall thickness of a 16 S.W.G. pipe), in five years. Lead was unattacked in one soil and moderately attacked in the other four, with maximum depths of attack between about 0·5 and 1·0 mm. (7–15% of a ¼ in. wall thickness) in five years. Lead behaved comparatively well in the cinders. It was worth remarking that they had encountered variation of corrosivity along the length of the trench by a factor of two.

Joint Discussion

DR. F. A. CHAMPION (British Aluminium Co., Ltd.) questioned whether the results had been presented in the best possible way. He would have preferred a simple plot of corrosion against time which might reveal that the corrosion effect was considerable in the first year, decreasing in subsequent years more in salted than in unsalted soils.

Dealing with the second paper, he referred to the breakdown of the protective oxide film on aluminium at three sites, he suggested that the sulphate and chloride explanation was insufficient and further attention should be paid to copper contamination.

He was interested by the suggestion of puddled clay protection and thought that it might be applicable with aluminium, especially if the clay were puddled over the bitumen/barium chromate type of protective coating, which was giving promising results in soil corrosion tests made by his colleagues.

MR. GOSDEN found it hard to draw firm, general conclusions before correlation of the nature of the soil and the amount of corrosion was possible. The results

did indicate that copper earthing strips would be suitable in most natural soils, and that aluminium needed a more permanent covering to be used underground.

Of 130,000 miles of buried cable belonging to the British Electricity Authority, most had some sort of protection. The standard was two bituminised paper tapes, two bituminised cotton tapes and one bituminised hessian tape. This was quite good against chemical attack, though it was not so good against stray currents in which armouring was necessary between the cotton tapes and the hessian. There had been 106 faults due to corrosion in 1949–50, i.e., 0·08 per year per 100 miles. Of these, 63 faults had been due to electrolytic attack (29 due to stray currents), 27 were due to chemical attacks, of which five had been accounted for by local contamination and most of the others by aggressive soil. The causes of 16 corrosion failures were unknown.

MR. J. B. COTTON (Imperial Chemical Industries, Ltd.) thought that, from the weight loss figures quoted in the paper, the order of merit in which tinned copper appeared to be superior to bare copper might be misleading, particularly if the results were too widely interpreted. No assessment of pitting had been made, and he doubted whether one could accept the general usefulness of tinned copper for underground use in spite of the good showing in the test. He would not like to see tinned-copper pipes used underground. He queried the general usefulness of the tests for the particular application under discussion, since the work had not involved the application of impressed current to the specimens.

MR. E. A. G. LIDDIARD (Fulmer Research Institute) regretted the attribution of the paper to the Electrical Research Association, instead of to individual authors. He thought that the best way of using aluminium underground would be by protecting cathodically with some suitable cladding, such as the aluminium/zinc coatings that were being used in the U.S.A.

MR. R. L. DAVIES (British Insulated Callender's Cables, Ltd.) suggested that aluminium might not be trustworthy in anaerobic conditions. When immersed in distilled water, boiled and sealed with paraffin, the aluminium gave off hydrogen after four weeks and began to corrode. The access of oxygen would appear to be an important factor. When tested similarly in a nitrate solution, the aluminium specimens, after a period of a few days to a few weeks, began to dissolve very rapidly, the nitrate having turned to ammonia. Could this not happen when aluminium was buried in soil ?

Author's Reply

Replying, DR. G. MOLE agreed with Mr. Cotton that care should be exercised in applying his results to pipes, since pitting was of no significance in earthing strip and had, therefore, been disregarded in these investigations.

DR. GILBERT in reply to Dr. Champion's suggestion of further investigation of copper contamination in the electrolyte when aluminium corroded said the matter would be pursued. The presence of chloride and sulphates was not necessarily detrimental, but breakdown would be more rapid in the presence of chloride.

" Safety " Colour Code

DURING recent years Industry has given increasing attention to colour coding of danger points in factories to indicate high voltage lines, toxic gases, and obstructions such as low doorways and steps and other varying degrees of hazard, and a Committee of the British Standards Institution, representative of a wide variety of experience, has been considering the possibility of preparing a " safety " colour code in order to secure unification of the present different practices.

The Royal Society for the Prevention of Accidents made an extensive enquiry on behalf of the committee, as a result of which and of other investigations, it has now been decided to abandon the attempt to prepare a code. As the reasons for this decision will be of interest to all sections of industry, they are set out below.

Examination of the problem showed that a distinction must be made between a *safety* colour code and an *identification* colour code—the purpose of the former being, broadly, to classify types of hazard and to give warning of them by colour, whilst the object of the identification code, as in the British Standards 1710 for pipe lines and 349 for gas cylinders, is primarily to identify by colour the contents, and any application to safety is incidental.

It was the former type of code that the committee had to consider, and it was found that many colours had traditional connotations, which whilst not always consistent, were so well known that they could not be reconciled.

The second difficulty was that the only truly satisfactory method of ensuring safety is to eliminate the hazard, and the committee felt that a code might encourage identification of hazards by colour instead of their removal.

Thirdly, the increase in the scientific use of colours for decoration to secure better light and to improve working conditions detracted from the effectiveness of a safety colour code, and these schemes of colour treatment were considered to be more effective in the reduction of accidents.

A fourth and important point arose from positive evidence submitted showing that the significance of colour codes put into effect had been quickly forgotten ; whilst this is relatively unimportant in the case of an identification colour code where time is not vital, it was felt to militate seriously against the use of a safety code where recognition and significance of colour must be immediate and instinctive.

Copper and Zinc Restrictions Postponed

MANUFACTURERS of goods in which the use of copper, zinc and their alloys was banned by a Ministry of Supply Order in November—household appliances and electrical, gas and builder's fittings were among the articles listed— are to have a further twenty-day period in which to finish partly-made goods containing the metals.

The original order (The Copper & Zinc Prohibited Uses (Ministry of Supply) (No. 2) Order 1951, S.I. 1951 No. 1960) gave them until February 1st, 1952, to use up stocks of fabricated or partly-processed zinc and copper. A new Order is to be made extending this period until February 20th, and making amendments to the list of prohibited articles.

A New Version of "Strength of Materials"

By Archibald C. Vivian, D.Sc., F.I.M.

In 1940 the author became interested as a lecturer in elucidating the atomic or lattice changes responsible for changes in mechanical properties under metallurgical treatment, and in the course of his studies he became extremely critical of the generally accepted system of " Strength of Materials." In this article the case for the new version of the subject is presented.

TECHNICIANS, notably mechanical engineers, engineering draughtsmen and metallurgists, are trained in a technology of the mechanical properties of materials, often called " Strength of Materials," which in some ways is an anachronism to-day. It has neither the unifying conception necessary in any system, nor a purposeful, rigid terminology, nor any symbolism of its own : it is incoherent and even contradictory. Physicists and mathematicians, in their occasional and independent approach to such matters, have not actually subscribed to the weakness of the technician's outlook, but, on the other hand, they have never denounced the standard version, nor yet substituted order for chaos by building anew on a sound foundation. Moreover, physicists and mathematicians are bound to rely on technicians for accurate information about the behaviour of materials under load, and it is impossible for the former to have correctly-stated problems to solve—more than likely, in fact that they will be misled—if the latter are themselves mistaken owing to their own employment of an archaic code. The task of devising a new system has been the writer's interest and concern during the last ten years.[1] Part of the following has already been published in this journal and elsewhere, but the whole is now presented in a more finalised form.

" Strength of Materials "[2]

In all probability the development of an ancient art into a modern technology rarely takes place smoothly, but rather tends to proceed in strides from the inception of aims to the perfection of their means of attainment, then back to a reconsideration of aims, and so on. It is tenable that development in engineering and metallurgy during the last fifty years has resulted in the carrying of " means of attainment " as far forward as they are likely to go with ease until a new step is taken to reconsider " aims." For, by contrast with the energy and understanding put into actual operations by metal workers and other craftsmen of to-day, the fundamental standards by which they are still directed are characterised by no little weakness and misconception.

At the root of the trouble with these basic standards lie lack of system, loose conceptions and vacillating terminology. From the systematic study of "Mechanics" we turn to " Strength of Materials " with something akin to dismay, for, instead of finding in it an allied type of applied mathematics, we observe that all sight has been lost of the elementary necessity to retain specific words

as terms to convey single rigid ideas, so that calculations are hardly possible, in fact a severe handicap is imposed at present upon the transmission, recording, and handling of the plain facts about materials.

In this technology, we find that the word " resistance " can mean unital force, a ratio (as in " creep resistance,") or an amount of energy (as in " impact resistance."). " Strength " at various times means all the properties which are stresses : in the minds of some it even includes those measured as strains ; sometimes it refers narrowly to a false, sometimes to a true, maximum stress. We never inquire too closely what " hardness " may be, but we put it aside by itself, and then speak of " strength and hardness," usually meaning by this all the stress properties; we prefer to speak of " hardening " without referring in particular to any increase in the opposition to indentation, but merely to describe the raising of the stress properties in general. Each of us is permitted to work out independent ideas of " toughness " —or rather of " brittleness," because, for some unknown reason, the negative property has always been the more respectable of the two in this particular case. We have been told how complex and subtle " toughness " really is : it certainly must be complex if it has to represent the average of whatever metallurgists and engineers have felt it to be. But why do we adopt this attitude ? In " Mechanics," " work " is an absolutely fixed and simple thing, having definite dimensions with which no one may tamper ; it is not permitted to be the average of all that so many interested persons have thought about it ! " Ductility " is commonly defined in one way and tested in another way whereby we get a " nominal " or wrong result ; there is often quite a definite feeling about this property that " softness " is involved—but not " weakness," because the latter word is permitted to convey feelings of uncertainty of behaviour rather than the simple opposite of strength.

To make further progress, it seems highly important that all concerned should, for the time being, *cease to feel* so many different things about the behaviour of the materials under load. For the moment, we should adopt a precise terminology, and learn to handle it in an unequivocal way, if not in a mathematical way. Adequate visualization will then follow, our thinking and feeling will be in line with our practical tests, and, as it will be seen, mathematical handling will soon come.[2]

The Shape of a Material's Reaction to Force[3]

At one time, a good many people thought the earth to be flat and, no doubt, some became so steeped in the notion that difficulty was entailed in escaping from it—

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[1] The necessity for reform and the new basis of a suitable version were both urged by the Author in a letter to *The Engineer* of March 14th, 1941, and his first paper on the subject was accepted by The Institution of Mechanical Engineers on September 8th, 1942, and published by the Institution, in its Proceedings, in September, 1944.

[2] Proceedings of the Institution of Mechanical Engineers as above.

[3] " The Shape of a Material's Reaction to Force." *Metallurgia*, **31**, 225–229, 301–307.

difficulty shared, of course, by any attempting to go to their assistance. The campaign of assistance to follow in these pages could be said to involve similar and perhaps even greater difficulties, comparable only with the above if, in pursuing the same analogy, a special supposition is made.

Let it be supposed that, in the past, people had not actually been " flat-earthists," seeing that they had never entertained—far less contemplated—the possibility of the earth having any shape at all ! But, for all that, be it supposed that they had arrived at certain limited conclusions about the earth's *weather*, for example, beyond which they could make no further headway. In order to overcome such a deadlock, clarify the position, and point the way to a fuller understanding, it might have become necessary to show that : (*a*) the earth could, and did, possess shape ; (*b*) the existing ideas of weather were tenable only on a flat earth ; (*c*) more precise details and advancement of knowledge of the weather could only be reached by the more tenable assumption of a round earth.

Major difficulties would be presented if questions of shape were quite neglected in attempts to solve geognosic problems.

As a body, the technicians to whom the new approach to mechanical properties is meant to appeal are hardly aware yet that these properties can be considered as parts of a system, of a scheme of a particular shape ; far less have they visualised the shape. On the whole, they have been viewing each property separately as little more than a " something " evaluated from an arbitrary test by means of calculation from measurements made therein. They resemble the above hypothetical people who tried to fathom weather problems without knowing that the earth had shape. Their superficial views served immediate and useful ends ; but these were limited ends which would lead on to no progress and discovery.

It is, therefore, submitted that, if engineers and metallurgists are as vitally concerned with the mechanical properties—the reactions of materials to force—as in fact they are known to be, it must be vital for the future progress of their technologies that they should appreciate the system of relationships existing between the properties, the fundamental shape of the scheme of which the properties are but closely related individuals. If it be reflected that such technologists might be as heavily handicapped nowadays as electricians would be without their exact system of units related by Ohm's and other laws, then it would seem to be worth-while to investigate the possibilities of a much more satisfying basis than that upon which " Strength of Materials " now stands.

The Proposed System

The proposed system, like so many others of potential and heuristic value, is simple. Technicians have been plotting " nominal " stress-strain curves, and perusing so-called stress-strain diagrams for a long time, but have yet to see how one suitable stress-strain curve is a complete statement of all mechanical properties of the elementary kind, whilst certain other properties—hardness, fatigue endurance, notch-toughness and damping capacity—are derivatives or compounds of the same. In the electrical analogy—current, voltage resistance, etc., are elemental, and are compounded in heating effect, electromagnetic effect, etc.

Four or five obstacles of a widely different kinds have hitherto blocked the road to a better understanding, their very diversity accounting for the fact that one or other, or a combination of these difficulties, has proved too great for the formulation of any simplification of the whole subject. To describe these difficulties is to explain a good deal.

Conceptions of Properties

Probably the most widely experienced difficulty has been the general impression that the conceptions of the properties, such as of elasticity, hardness and toughness, have, in themselves, a cardinal or elemental value, and that, to be adequate, the tests should provide results in accordance with this implicit belief in the primary significance of certain preconceived ideas and mental pictures. Such a subtle and psychological viewpoint has been unfortunate. A quality like hardness may, through personal reactions, be appreciated and identified sufficiently well for the mental picture, and for the planning of the practical test to elicit (what is described as) " hardness," but what can thus be known of hardness as the *reaction by the materials* to that particular type of loading ? Obviously nothing. Only upon examination of the mechanism of the reaction can hardness as a property of materials be understood at all. On examination, the mechanism of any test may prove surprisingly simple, resembling some familiar mechanism ; on the other hand it may prove to be complex and incomprehensible except through its mathematics. In fact, the original conceptions of the properties, having served their purposes in suggesting types of test, have been outlived. The analyses of these tests have frequently pointed out the inadequacy—sometimes even the inherent falsity —of the very conceptions which gave birth to the tests. The conceptions have been the probes by the use of which considerable advances have been made in understanding the reactions of materials to different kinds of force application ; the understanding, or rather the reactions themselves, are the only mechanical properties of any significance for the future ; the " probes " may now be forgotten.

Yet, awkwardly enough, the above difficulty of approach to the matter will not have applied in every case. Some of the properties have no traditional background, and minds have remained unbiased, happily fancy-free, towards them. The proof stresses, for example, and fatigue endurances are properties around which minds have weaved no spell ; they and some others have always been just what the mechanism of their tests prove them to be. It seems to have been agreed that a material's fatigue endurance cannot bear such resemblance to a man's endurance as to be dismissed as something quite familiar. Examination of this mechanism has revealed much, and " fatigue endurance " conveys nothing to the mind but the revealed mechanism.

Tensile, Compression and Shear Tests

The second obstacle is by no means subtle ; it involves no psychological difficulty of approach, and seems to call for a few well-chosen words which shall not mince matters. It might be described as the result of an ingenuous, if not a culpably artless, approach to considerations of stress and strain. The tensile, compressive and shear tests to destruction are carried out by recording the deformation taking place as the load steadily

increases, by calculating the stress from the load and area, and the strain from the deformation and length, and by plotting the stress against the strain to obtain stress-strain curves. If stress and strain are deliberately miscalculated for the sake of convenience, or for any of the reasons given in extenuation of such a crime as the "nominal" type of curve, then the curves derived from tensile, compressive and shear tests have very different shapes.

If stresses and strains are calculated properly, however, then the curves for tension, compression and shear are quite similar in shape, and conviction grows that experimental errors and/or purely secondary reasons (of comparative unimportance to the generalisation itself) must be responsible for the small differences between them.

Loading Differences

The third obstacle is only a matter of detail—of vitally important detail, however. It is the difficulty that there are those small differences between the curves of the three types of loading, even if stresses and strains are calculated properly.

It has been appreciated that the results of the compressive test are incorrect if lubrication is not provided between the ends of the specimen and the jaws of the machine, friction at these points being obviously undesirable and likely to yield erratic results. Sheet lead is sometimes introduced for lubrication purposes. But this is only one recognition of a general truth which has not been so generally recognised—that, in all these tests which are to be comparable, the lateral strains must be entirely unrestricted. It can be seen that the shapes of these stress-strain curves will be profoundly affected by restriction of the lateral strain. In fact, the normal long, low curve of the ductile material may even become the steep, straight-line volume compressibility curve if complete restriction of the lateral strain is applied. The foregoing statement seems to have occasioned little or no comment or curiosity since it was first offered by the writer some years ago: the question therefore arises whether technicians realise its significance, or know that the proof of it is to be found in popular engineering "Strength of Materials" textbooks—not in so many words, but by easy deduction from elementary formulae. As described later, hardness stress differs from ordinary axial stress only on account of the degree of restriction of lateral strain which is provided by a sufficient excess of the material itself around the central area of compression in the test. Such a degree of restriction is very far from complete: no known material provided around the core under compression would procure complete restriction of lateral strain on account of the elasticity of all materials. Nevertheless, if an experiment were conducted with an application of external force around the core specimen, which ensured no lateral strain development whatever, then the stress-strain curve would be the steep straight volume compressibility line. Therefore, no compressive test curve is exactly comparable with a tensile test curve unless its specimen is literally unrestricted by external forces in its lateral deformation. Moreover, in the torsional shear test, radial fibre shear is never unrestricted, and only becomes relatively unrestricted in tests on thin tubular sections.

Attention to vital details, of which the above are only two out of several possible causes of differences in shape, would be found to remove this particular obstacle.

Homogeneity and isotropy have to be assumed in any generalisation and these are necessarily lacking in some well-known materials.

Measuring Strain

Obstacle No. 4 is as serious as any. The one true stress-strain curve obtained by the removal of the last two obstacles approaches the shape of the true characteristic curve of the elementary mechanical properties, but suffers from one embarrassing feature. The area underneath the characteristic curve should, undoubtedly, represent the work of reaction by the material per unit of its volume. Unfortunately, the area under the curve obtained up to the present does not; it can be shown experimentally that it does not, and examination of the actual units employed shows that it cannot.[4] The difference between the correct work of reaction per unit volume and that estimated from the usual* curve may be as much as 50% or so.

The difficulty here is that the common method of regarding and of measuring strain happens to be unsuitable; it can be overcome quite simply by changing the method, changing the commoner conception of strain to one which is not so common and perhaps a little tiresome at first. As usually conceived, strain is $(l - l_0)l_0$, or deformation by unit of original length; but, as this can only apply properly up to maximum uniform deformation, the complication in the case of a specimen with necks or bulges is adequately looked after by the formula $(A_0 - A)/A$ applied to the neck or bulge. The conception of strain is identical in each formula, and it will not satisfy the work-reaction requirement of the true characteristic curve.

The type of strain required is that which may be described as "differential" or "logarithmic."[4] It is the sum total of a vast number of infinitely small changes in deformation, each divided by the length actually undergoing deformation. Where ordinary strain is s, or $(A_0 - A)/A$, this differential strain is $2 \cdot 3 \log (1 + s)$, or $2 \cdot 3 \log (A_0/A)$. This less common kind of strain is simply related to the common kind, and there can be no more objection to making such a change than in changing from a fractional basis to a percentage basis, or from density to specific gravity, or from Centigrade to Absolute degrees of temperature. If desired, the usual kind of strain can still be used in measurements of ductility, or for any purpose except that of measuring the specific work-reaction of a material. The correct work reaction can be expressed by quite a simple formula in terms of the usual strain; no disturbance is strictly necessary, though it would be advisable to become accustomed to the idea of this more satisfactory type of strain.

Compound Properties

The fifth and, perhaps, the final obstacle to the acceptance of one true stress-strain curve to stand for the mechanical properties, is the undeniable fact that all the mechanical properties are not exhibited on such a curve. What then, are toughness, hardness, notch-toughness, and fatigue endurance?

It will have been noted that toughness has just been dealt with; it is, in fact, the specific work of reaction by

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* This refers to the most enlightened curved used hitherto, which employs $(A_0-A).A$* strain; it is in reality far from "usual." True toughness may be four or five times that shown under the "nominal" (or most usual) curve.
4 The Author's paper "Fracture: its Energy Distribution and Specific Energy." *Engineering*, June 2nd, 1944.

work per unit volume, up to any desired point of stress and strain, up to fracture point if desired. It is similar to proof resilience, the latter being mainly elastic toughness, while plastic toughness carries on beyond the "elastic limit," and a progressively smaller part of it is reversible energy. Toughness is the first compound property, and it can be read direct from the curve employing differential strain.

Meanwhile, there are numbers of tests for materials, specimens and special machine parts which have not yet yielded figures of merit ranking high as standard properties. Attention is drawn to one of the most elementary of these, because light can be thrown on the whole question of the compound properties by examining the following simple case.

A coiled spring is an example of a special machine part which may be required to undergo a test for, say compressibility. Now, the mechanics of the spring's action is known ; let it be supposed that it is, in fact, quite accurately known, and that a perfect stress-strain curve of that material is at hand. In such a case the test itself should be quite unnecessary, because the compressibility of that spring could be *calculated* with ease.

In the same way, there can be no compound property, of which the mechanics, or mechanism, is really understood, that cannot be calculated with the aid of the true curve of the material. From such a rule there would be no need to exclude fatigue endurance, hardness and notch-toughness if the mechanisms of the material's reactions to these types of loading were really known. When the above mentioned properties can be calculated they should give greater satisfaction than they do now ; for, by the time they can be calculated, they will undoubtedly be understood.

Toughness[4] for example, may now be calculated from the stresses (f) and the logarithmic strains (s) by measuring the area under the true curve thus :—

$$\sum_{s\,=\,o}^{s\,=\,s} f.ds$$

and, if the curve shape can be identified by some such formula as $f = ks^n$, toughness can be calculated without area measurement from :—

$$k. \int_{s\,=\,o}^{s\,=\,s} s^n.ds \quad \text{which is} \quad \frac{ks^{n+1}}{n+1}$$

This seems to be an exemplary case. If toughness means specific reaction in work per unit volume, and if it is agreed that the area under the true curve measures that property, there can be nothing further to be said about toughness. For, it is a property clearly seen to be compounded from the elements of the true curve in a certain manner. By the criterion of the ability to synthesize a compound property from its elements, toughness is seen to be completely understood.[3]

Toughness and Notch Toughness[2]

Simple considerations of thermodynamics suggest that the amount of energy necessary to overcome the cohesion in, or otherwise to sever, unit volume of a metal must be the same whatever form of energy is employed, whatever the number and variety of stages adopted, and whatever the time taken in the task—as long as energy is neither wasted to surroundings nor strays into the system from surroundings. Since the energy to effect severance of unit volume by heat is the same as that required to melt unit volume, this amount of energy must be the specific heat multiplied by the temperature rise to the melting point plus the latent heat of fusion. Expressed in work units, this energy should represent the ideal true ultimate toughness.

The true ultimate toughness of a metal when obtained from a mechanical test, must depend however upon the efficiency of the utilization of energy in the test. The laws of thermodynamics invoked for the above purpose provide for loss neither by conduction and radiation, nor by any physical change other than the destruction of the lattice, nor by any chemical change. For the sake of brevity, all these interferences must be referred to jointly in the category of "loss." The more rapid the application of work in the tests, the lower will be this loss (since it takes place chiefly by conduction and radiation in the standard case) and the more will the true toughness correspond to the amount of energy as calculated from the heat properties—specific heat, melting point, and latent heat of fusion. It will be smaller, then, at the higher rate of loading, approaching the minimum or heat-calculated quantity at the highest rates ; it will be larger at the lower rates, since a more protracted test will result in greater loss.

Toughness has been treated hitherto as though synthesized from the more fundamental stress and strain, which are both known to vary with loading rate. Considerations of thermodynamics suggest the identity of the ideal true ultimate toughness with the total heat needed to melt unit volume, showing that the energy to fracture is as fundamental and primary as it could be—even though it may be capable of analysis into stress and strain. If ideal true toughness is viewed as the fundamental constant minimum for any particular pure metal or alloy, it will be possible to see why variations in loading rate do, in fact, produce the known effects on stress and strain.

The inertia of the atoms (small masses under large cohesive forces) will account for the higher stresses of the higher loading rates ; whereupon the principles of thermodynamics step in and call for lower strains in order that total energy should remain constant. When at very high loading rates, inertia has maximum stressing effect but loss is very low, the high-stress low-strain product will be very low, approaching the heat-calculated "adiabatic" type of change. When, at very low loading rates, inertia has minimum stressing effect but the loss is maximum, the low-stress high-strain product will be very high because of the "isothermal" nature of the change in which much energy is lost to surroundings.

True mechanical toughness must, then, depend on the loading rate : in any test, the true product of stress and strain at any stage must vary with the time of the test. Expressed in a different way : as loading rate falls from infinity, strain varies (inversely and) faster than stress, owing to the smaller efficiency of the lower loading rates in the process of severing the metal. The true toughnesses of metals are therefore worth having ; for they can only be the same as the toughness calculated from the heat properties at an infinitely high loading rate, being greater than this on account of the energy loss in the mechanical test. Space does not permit of reference here to the elastic increment of toughness, or to any of the other attractive developments of this theme.
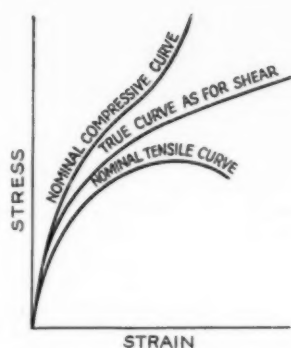
Fig. 1.—Nominal and true stress-strain curves for tension and compression. (Slopes of moduli greatly exaggerated).

Fig. 2.

Notch toughness is now seen to be quite a different matter. This is no unital energy to fracture the metal with an excessively high loading rate developed at a notch ; for, whilst the total energy to fracture is taken as the measure of the notch toughness, any examination of the localities of fracture behind the notch will reveal that very different volumes of the metal are involved in the fracture (see Fig. 2). So large are these differences that by far the most important consideration in these tests must be the volumes which become involved in these fractures—specific energy falling into the background in the great majority of cases.

Hence, a notch-tough metal is merely one causing a spreading of the energy beyond the notch—as effected by grain refining. A notch sensitive metal is one in which the spread of the energy is inhibited either on account of coarse grain, or owing to casual or inherent internal notches, or else because the metal contains some potential mechanical, physical, or chemical energy by which it rips itself as soon as the excessively high loading rate at the notch acts as a trigger to release that energy.

As between two metals with equal capacity for spreading the energy of impact, evidently the tougher of the two will prove to be the more notch-tough. Ordinary toughness will therefore play some part occasionally, being the deciding factor in any case which is doubtful from the standpoint of strict notch toughness. At the higher rate of loading—and in particular at the exceptionally high rate obtained at the notch itself—this ordinary toughness should be lower than that of the tensile test, and even more difficult to calculate than that of the tensile test.[2]

Hardness[5]

It is now becoming possible to do rather more than conjecture how hardness may be synthesized if it is viewed in a forthright manner as strength, elastic and/or plastic axial stress reaction, greater than that of the true curve on account of the lateral strain restriction characteristic of different materials subjected to local or central loading. A recent analysis of the Brinell test shows that, under hardness conditions of lateral strain restriction, the ordinary strength (the stress of the true curve) is increased by the factor $(m - 1)/(m - 2)$ where m is Poisson's Ratio, or even when it is an apparent Poisson's Ratio in plasticity.

5 The Author's paper "An Analysis of Hardness." *The Philosophical Magazine,* November, 1944.

In the case of hardness loading on " work-hardening " materials, for any given degree of axial strain induced in the material, indentation strain for example, the corresponding axial stress is $(m - 1)/(m - 2)$ times as high as that to be expected from the true stress-strain curve. The published values of m apply to what is known as the " elastic range " only, as Poisson's Ratio is supposed to be an elastic property. Any degree of plasticity (while it lasts) causes this ratio of the axial strain to the lateral strain to fall, ultimately to a limiting value of 2 in the fully plastic or liquid state. As m falls, the value of $(m - 1)/(m - 2)$ rises, presenting a complication into which, fortunately, there is no necessity to go here and now, for the true curve is also what has been known as the " strain-hardening " curve ; and, by the time any stress of the plastic range has been induced for a short time, this strain hardening has so altered the stress-strain characteristics of the material that the comparatively straight part of the curve—the so-called " elastic range "—has risen up to the value of this erstwhile plastic stress. The published values of m are now applicable once again, since the material's " elastic limit " has risen to the value of the original plastic stress sufficiently for their use.

Hence, if a maximum strain (in single loading), a fracture or rupture strain, is induced in compression at the surface of a steel by the indentation of a very hard ball, the " strain hardening "—or (more properly speaking) the strain strengthening—has soon raised the " elastic limit " of the material to the fracture stress, say, 65 tons/sq. in., at least sufficiently for the use (without appreciable error) of the usual value of m, which is 3·3 for such a steel. In this case the factor $(m - 1)/(m - 2)$ becomes 1·77. Therefore, the axial stress required, under hardness loading conditions, to produce this effect of fracture is $65 \times 1·77$ or 115 tons/sq. in., or 180 kg./sq. mm., which is the *Brinell Hardness Number* itself for such a steel, the hardness stress near the *surface* where the maximum possible strain (by single axial loading) has been induced.

Similarly, for example, if at some depth below the Brinell ball some strain, such as that of a 25 tons/sq. in. " elastic limit," is found to be induced, then the relevant axial stress—to which the Brinell number has degenerated at the depth in question—must be $25 \times 1·77$ or 44 tons/sq. in., or 69 kg./sq. mm.

Thus, hardness may be synthesized from the elements of the true curve, and there would appear to be no further necessity to apply tests for it. Alternatively, it could be said, perhaps, that the only point in carrying out a hardness test to-day is that the test, a very simple one in itself, provides a compounding of m and of (single axial loading) fracture stress, neither of which are too well-known to-day, because they do not happen to have been carefully determined. Were the true curve and right values of m both available, there could be no more point in carrying out the hardness test than there is in carrying out a toughness test (already dealt with) on a material for which a true curve is available.[5]

Hardness in Tension

A criterion of the sanity and of the value of any new conception is the discovery to which that conception may lead. If hardness is, in fact, as described above, and if, also, compression and tension are identical in their true stress-strain curve, then an effect identical with that so commonly experienced upon compressing a small

central portion (of a sufficiently large area) of the material should also appear when tension is substituted for compression in similar circumstances. Is hardness in tension ever experienced ? Sketch *A* in Fig. 3 depicts
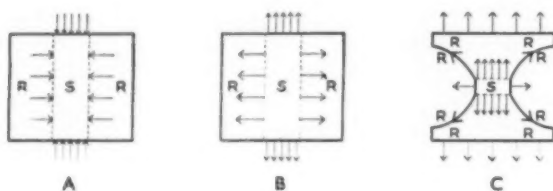

Fig 3.

ordinary hardness loading, the loading in compression of an internal specimen of the material marked *S* : Sketch *B* shows similar loading and restriction but in tension on the internal specimen. In both cases *R* represents the shroud of surrounding material restricting the lateral strains. Materials do not happen to be tested in the manner of *B*, but, many years ago, Dalby showed the effect of bringing the shoulders of a tensile test specimen nearer and nearer together, and found that the effect when the shoulders are as near as in Sketch *C* is remarkable enough to leave no doubt that restriction of lateral strain in tension puts up the apparent strength progressively with the amount of restriction. His curve of the effect (on apparent strength) of bringing the shoulders of the tensile test piece together is shown in Fig. 4.

Hardness in tension is exhibited also by tie-rods enveloped in concrete which has been made to bond well with the surface of the rods : such ties will exhibit strengths quite unexpected from their performances either outside the concrete or when fitted (without bond) through holes in it.

Toughness and hardness have both been demonstrated, then, as examples of compound properties capable of being calculated like the compressibility of a coiled spring. It can be surmised with fair accuracy that fatigue endurance, damping capacity, notch toughness, as well as any of the lesser lights amongst the properties will similarly lend themselves to calculation from the elements of the true curve.

Turning, now, to remaining properties which cannot be read directly from the curve, they appear to be compounded in one way or another from the elements of the true curve. Neither fatigue endurance, nor notch toughness are true " unital " properties, as their figures of merit do not relate to lengths, areas, or volumes in the same unequivocal sense in which all the elementary properties and toughness relate.

Fatigue Endurance

The measure of fatigue endurance is nowadays the fatigue " limit," which is a stress. Yet, this stress of the *S*–*N* curve is of a hypothetical nature, not directly applicable to the precise localities of failure, but rather to a miniature area of maximum stress at the critical section where many failure localities are to be found. At the precise localities of failure, the elemental properties must apply honestly enough ; but it is only the statistical average effect of the operation of these elements at a number of separated localities that is reflected in this hypothetical " limit." Moreover, failure follows a great

number of repetitions of such stress induction, and for this reason alone the latter is as different from the stresses in the standard tests of (single) tension, compression and shear as anything could be.

The measurement of fatigue endurance as a " limiting stress " is a device which serves a very useful purpose, but, like the " ultimate tensile stress " has no reality as a unital property of materials, and should be regarded as only nominal. It is not improbable that fatigue endurance will, in time, be measured in terms of energy and volume as a property compounded from the elements of the curve in some way at present uncertain.

The discovery of the formula by which to *calculate* fatigue endurance (instead of performing the test) calls for the efforts of one very well versed in fatigue phenomena, pretty good at applied mathematics, and supported by a belief in the probability of success based upon the results already obtained in the case of toughness and hardness. The writer owns to defeat in his attempts, and ascribes this to his weakness in the field of mathematics, but he has nevertheless approached to within visible distance of the goal by investigating the progressive propagation of hair-cracks on the surface of the fatigue endurance specimen at the critical cross-section of maximum stress. By this means some progress appeared to have been made in computing the increasingly more rapid rate of the inward travel of such hair-cracks ; and, by transposition of energy equations, a relation of *N* and *S* appeared which was logarithmic. It seemed possible that *N* could be equated to a power of exponential *e* containing a power of *S* which accounted for the manner in which a rather flat-lying part of the *S*–*N* curve can be found at which *S* can be called a " safe stress " in many instances. It is the writer's belief that the very flat-lying part of the *S*–*N* curve to be found in many other instances is due to the same cause as that producing the very straight stress-strain curve commencement of even the mildest steel. In fact, it seems to be an attractive possibility that, like the hardness curve, the *S*–*N* curve is a certain type of modification of the true stress-strain curve, the near-elastic and elastic portions of which (modified by some unknown factor) are, in reality, the interesting part of the *S*–*N* curve.
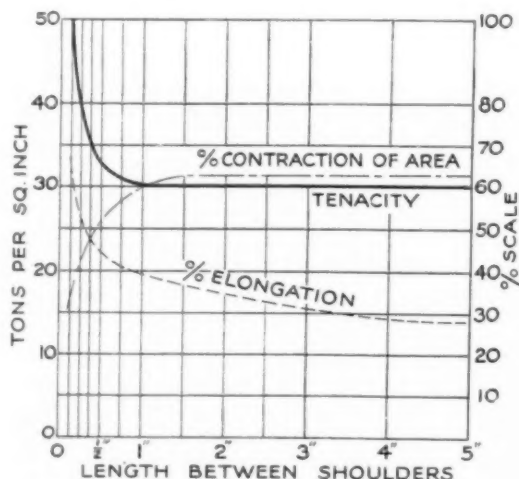

Fig. 4.—**Effect on mechanical properties of distance apart of test piece shoulders.**

Damping Capacity

Under vibration, or repetitions of load reversal at high speed, in the near-elastic range of stress, materials absorb very different amounts of energy per cycle; those absorbing more are said to have higher damping capacity than those absorbing less, for they tend to damp oscillations which would otherwise tend to build up to induce really damaging stresses.

The hysteresis loop upon which this phenomenon depends is completely dependent on the shape of the true stress-strain curve. This latest of the properties to be recognised as important is very closely related to the true stress-strain curve, and a " Proof Resilience " at the relevant loading rate would almost certainly be an adequate measure of it.

One True Curve[3]

The one true curve, to which reference has so frequently been made, is the graph obtained on testing at room temperature and at a rate of loading which involves the fracture of the specimen in a minute or so. Now, the loads, deformations, lengths and areas whose measurements permit the construction of the true stress-strain curve have not usually been measured with a high degree of accuracy, because the materials tested have lacked the high degree of homogeneity and " repeatability " which would make it worth while to measure accurately. In consequence, comparatively large changes of temperature or rate of applying load in these tests will pass unnoticed in the shape of the stress-strain curve of a material. Yet, literally, the true curve can only be of fixed shape at exactly one temperature and exactly one rate of applying the load. The shape depends, then, on both temperature and loading rate, or time, and this fact would be perfectly apparent in the testing carried out under slight variations of temperature and time, but for the fact that the measurements are not made carefully enough, nor is the available material " repeatable " enough. Whenever such testing is carried out at temperatures and times greatly differing from the normal, differences in curve shapes become apparent in spite of crude materials and measurements.

In general, the effects of temperature and time on the curve shape are as follows: high temperatures and " high " times (slow loading rate) make the curve flatter and longer, and vice-versa. There are some complications in the important cases of iron, copper and their alloys. It would seem to be possible to ascertain the shape of a material's curves at a variety of temperatures and rates of loading, and to express differences in these shapes by means of some kind of coefficient to be applied to a standard curve shape. This might not be as difficult in practice as it sounds; because it is usually possible to apply a logarithmic formula to the curve shape, and the variation in shape with temperature and time change could then be indicated by changing values of k and of n in such a logarithmic formula as $f = ks^n$.

Even somewhat rough approximations to the mechanical properties at different temperatures and times would be much better than none at all. Up to the present, very little attention has been paid to determinations of the curve shape at temperatures and times greatly differing from those which have come to be considered " normal." Some curves showing how individual properties change with changing temperature are available, and a little work has been done in the direction of discovering the effect of a changing loading rate. The new outlook on the properties suggests that the reasonable thing to do is to provide a standard stress-strain curve with co-efficients by which to calculate from it the shape, under conditions which are abnormal in testing, but which may be quite commonplace in forging, rolling, pressing, extruding, drawing, and so on.

Elasticity

The study of the curves of certain crystals has suggested the literal reality of an elastic range terminating in a limit of proportionality and/or an elastic limit. However this may be, there is no material of construction like this; in spite of the fact that wrought iron and mild steel superficially appear to be elastic up to points in their curves where a discontinuity occurs and plasticity begins, it is true to say that all materials react to force with a combination of elastic and plastic reaction from the beginning of the curve to the end.

For a few important practical purposes, of course, there may be nothing but usefulness in assuming the truth of Hooke's Law up to some limit of proportionality, and in assuming some elastic limit for a material; in such cases, there may be a practical assumption without any literal reality in these limits. But the literal reality asserts itself in no uncertain way when liberties are taken with it, when attempts are made to discover the stage of strain amounting to " mechanical failure." It is then high time to point out that, in reality for materials, there is neither limit of proportionality, nor constant modulus, nor elastic limit, nor point where plasticity commences.

Nor, for that matter, can mechanical failure be said to take place after a specific amount of work has been done on the material, at some proof resiliences. For, " proof resilience " must also disappear with the " elastic limit."

Probably the best course for any disposed to think that there is a very strongly marked " elastic limit " in the case of some materials (such as the steels) is to examine a stress-strain curve of one of the steels, for example, with an extremely open strain-scale, as can be obtained by the use of an electronic extensometer. Then, what looks on the more usual strain-scale as the "straight line " to the " elastic limit " is seen to be a curve, upon which it is quite impossible to place a " limit of proportionality " or an " elastic limit." The more sensitive and accurate the device for measuring the so-called " elastic " deformation of any material the greater the conviction that there is no literally pure elasticity, and no stress, strain or work at which mechanical " failure " could be said to begin. Nor is there a greater degree of hope in any suggestion that " failure " could be considered to be at the sudden yield of the steels.[3]

The Applicability of the Expression

$$f = ks^n$$

If the specimen's size is sufficiently great in comparison with the size of its inhomogeneities and/or its areas of anistropy, and if the material suffers little or no sporadic or irregular physical change in consequence of loading, its whole stress-strain curve can be expressed quite closely by $f = ks^n$ where k and n are constants for any given temperature and loading rate. A typical example of sporadic physical change on loading is to be found at the commencement of the curves of certain irons

and steels in common use. This is a change which ceases, or is strongly checked, at the point commonly known as the "jogged yield point." Such curves start with a $f = k's''$ formula and continue with a $f = k's''$ formula to the end. If a substance falls short in homogeneity or in isotropy, or suffers irregular physical change during loading *within the range of stress induction necessary for some practical application*, then it seems fair to exclude it from the category of "materials" for that application. This provision does not exclude either cast iron or steel in common use, because neither is applied for the exercise of its mechanical properties within the range of its eccentricities in behaviour.

It is relevant, here, to ask the reader to experiment with this logarithmic equation by progressively (1) decreasing, and (2) increasing the value of n respectively below and above the value 1. It will be found that as n is diminished to a very small fraction, or as n is increased to a very large number, the curve assumes shape as (apparently, only) two straight lines at right angles to one another joined by a short bend. In the first part of the curve for the steels the value of n' in $f = k's''$ is extremely small.

It should be noted that the expression $f = ks''$ would fit even the most erratic of the true stress-strain curves sufficiently well to enable much more correct determinations of the plastic properties of those materials to be made than has hitherto been possible. This is because none of the plastic properties has been determined by the present-style mechanical properties with any approach to accuracy.

Technical Versus Scientific Approach

The comprehension of the mechanism of cohesion and innermost reaction to force in the great diversity of materials is, beyond doubt, an enormous undertaking upon which pure scientists are at work. But, that understanding of the innermost meaning must surely be of scientific rather than of immediate practical importance. The pressure-volume curve of a gaseous reaction to force, for example, is in itself a simple experimental result of the greatest technical and practical significance whether the Maxwellian or the Kinetic Theory of gases be true !

In the same way, the really significant stress-strain curve of a metallic aggregate's reaction to load is of the greatest technical and practical value even though scientists have hardly begun to discover the nature of the forces involved in that equilibrium known as the "lattice."

The most brilliant paper by the most prominent physicist upon the effect of external force on the particles of a metallic lattice could never be a quietus to a plea that technical and practical men primarily require that materials should be made to exhibit their true stress-strain curves at once, long before scientists and mathematicians have concluded their researches into inner truths. In the opening phases of the new study, "Rheology," in this country there has also appeared a tendency to assert the mathematical side of the subject when it would seem unlikely that this side could handle more than a practically non-existent hypothetical material. The practical man cannot await the result of difficult and protracted researches before availing himself of simple tests to provide curves of stress and strain, of viscosity, and so forth.

Present Significance and Future Potentialities

The writer's personal advantage in having lived with the new idea for ten years has enabled him to assess the likelihood of immediate usefulness and the hopes for the future of these proposals.

Engineers and metallurgists have founded an enormous edifice upon the old foundations and building still continues unchecked. Yet, we all know well enough that great structures were built in past centuries with still poorer tools than those we possess to-day. We look back in wonder at the efficacy of the ancient methods, even as future generations will marvel that our present structures could have been built with "Strength of Materials" in such a state of chaos.

There is something more, however, in the new ideas on the mechanical properties than there is in, say, the decimal system. The former has unearthed real criteria of ductility and of toughness which had not hitherto been appreciated at all. It has also shown how hardness can be calculated instead of measured, thereby indicating the true nature of hardness. In performing that service it has demonstrated the nature of the compound properties and suggested the necessity for a proper analysis of fatigue endurance to complete the picture. It has thrown light on elasticity, on the so-called point of mechanical failure, and on many other old beliefs.

The new picture which has been drawn of the effect of changing temperature and loading rate on the stress-strain curve clearly and simply indicates the nature of the changes in properties normally to be expected under those different conditions. The vital generalisation proved to exist with regard to these mechanical properties must ultimately throw a flood of new light in all directions.

The Effect on Metallurgy and Rheology

Metallurgical treatment is designed to effect changes in the mechanical properties, i.e., in the height and the length of the true stress-strain curve. The author's publications in the technical press[6] have already shown this and have classified all known metallurgical treatments by their influence on change in the curve shape.

Similarly, the author's publication in the technical press[7] has submitted a complete case in favour of considering Rheology as a special part of the New Version of Strength of Materials in which the time ordinate is more than usually important.

Acknowledgments

The author wishes to acknowledge his indebtedness for permission to include extracts from his earlier published papers, as set out in the list of references.

6 The Author's articles, "Realism in Metallurgical Treatment," *Metallurgia*, 29, 233–238 ; "A Logical Approach to Metallurgical Treatment," *Metallurgia*, 30, 15–17.
7 The Author's article, "The Relationship of Rheology to Strength of Materials," *Metallurgia*, 30, 237–240.

APPENDIX—SHORT SUMMARY

PRESENT STYLE MECHANICAL PROPERTIES
(Unrelated, unsystematic and faulty in conception)
Young's Modulus (f/s within the Limit of Proportionality) E. (Also C and K).
Limit of Proportionality (range of Hooke's Law).
Elastic Limit (beyond Limit of Proportionality ; the limit of true elasticity).
Yield Point (beyond Elastic Limit ; a sharp onset of plasticity).

Proof Stresses (usually at 0·1%, 0·2% or 0·5% strain).
Ultimate Tensile Stress (Tenacity) P/A_0 at maximum P (Load).
Proof Resilience ($f^2/2E$ where f is the Elastic Limit).
Ductility as Percentage Elongation at Fracture, $100(l-l_0)/l_0$.
Ductility as Percentage Reduction of Area at Fracture, $100(A_0-\text{s}A)$.
Creep Reistance (Strain/Time ratio at elevated temperatures and at fixed load).
Hardness (Brinell Test, Vickers Test, etc.)
Toughness (no test recognised ; some try to use the area under the nominal curve).
Notch Toughness (Izod Test, etc.)
Fatigue Resistance (Wöhler Test, etc.)
Damping Capacity (No test recognised).

NEW (INTERMEDIATE) STYLE MECHANICAL PROPERTIES
(All closely related by the true stress-strain curve)

Elementary Properties

Stress

Proof Stresses (at any desired strains, or at all strains).
Proof Moduli (tangents of the chord-angles at any strains).
True Fracture Stress (the Proof Stress at fracture strain).

Strain

Poisson's Ratio m.
True Ductility $\log_e(A_0/A)$ strain for final or intermediate true stresses).
Creep Resistance (True Ductility at very low loading rate, and (often) at some elevated temperature, starting at some selected stress induction).

Compound Properties

Toughness (area under the true curve using $\log_e(A_0/A)$ strain for final or intermediate true stresses).
Proof Resilience (same as toughness, but in the predominantly elastic straining up to some selected proof stress).
Hardness (for any given degree of axial strain induced by loading of the hardness type, the corresponding axial stress is $(m-1)/(m-2)$ times as high as that to be expected from the true stress-strain curve).

Notch Toughness as a " property " has been explained.
Damping Capacity as a " property " has been explained.[2]
Fatigue Resistance (analysis incomplete).

FINAL STYLE MECHANICAL PROPERTIES
(Related by three constants for each material)

Required : True Stress-Strain Curve, $f = ks^n$ and also Poisson's Ratio m.

The mechanical properties of a material are then k, n and m, three constants only, which themselves change for temperature and rate of loading. These constants, determined for a sufficient range of temperatures and loading rates can then be made to serve for every purpose now required and also for a great range of purposes hitherto unexplored.

Examples of Use

0·1% *Proof Stress* .. .. $k(0·001)^n$
0·1% *Proof Modulus* .. .. $k(0·001)^{n-1}$
Toughness (to fracture) .. .. $ks^{n+1}/(n+1)$

where s is the strain at fracture, or the true ductility at fracture ; for s can be substituted :

$$(f/k)^{\frac{1}{n}}$$

Proof Resilience (at some near-elastic stress such as $k(0·001)^n$
$$k(0·001)^{n+1}/(n+1)$$

Hardness $f(m-1)/(m-2)$, or $ks^n(m-1)/(m-2)$

This is the same as the Brinell Hardness Number (except that the latter is always quoted in kg./sq.mm.) if the f or s in the expression refers to the material's fracture point. In the correct conception, " hardness " is nothing more than the stress reaction of a material loaded to any degree but centrally only, i.e. not universally over the whole cross-section of the specimen, with a sufficient excess of unloaded material around the area of load application to effect the material's character-istic maximum restriction of the lateral strain of the load. The above expression means that, in all such " hardness " -type loading, the stress induced for any degree of strain developed is $(m-1)/(m-2)$ times that to be expected from the true stress strain curve, i.e. from the curve in which no restriction of lateral strain is tolerated.

British Standards Institution
New and Revised Standards
FILTER FLASKS (B.S. 1739 : 1951)

THIS British Standard is the first to be published for filter flasks, and in its preparation careful attention has been given to the requirements of users and to the manufacturing problems involved. Eight sizes of filter flask are specified from 100 ml. to 20 litre nominal capacity. Full dimensions and appropriate tolerances are given, but for a few dimensions temporary tolerances are also listed to cover present production in view of the manufacturers' heavy investment in moulds. For flasks over 250 ml. in nominal capacity an alternative form of vacuum connection is specified, consisting of a detachable side-arm fitted by means of a resilient grommet into a hole in the flask wall. A tapered neck is specified, which is convenient for use with a rubber stopper or can be ground with an interchangeable joint if required and other clauses cover quality of glass, general construction and wall thickness.

METHODS FOR THE ANALYSIS OF RAW COPPER
B.S. 1800 : 1951

THIS British Standard includes methods of analysis (sampling, apparatus, reagents and procedure) for the elements (except oxygen) for which definite limits are specified in B.S. 1035–40, " Raw copper," and B.S. 1172–74, " Deoxidised and arsenical coppers." A method for the determination of sulphur is also included although limits are not specified in the above standards. The methods have been found to give reliable and reproducible results and, while in some instances they

may appear to be lengthy, it should be realised that they are intended to be " referee " methods to be used in cases of dispute. Each method is distinct and is designated by a separate " Part " number.

Copies of these standards may be obtained from the British Standards Institution, Sales Department, 24, Victoria Street, London, S.W.1. Prices : B.S. 1739, 2s. and B.S. 1800, 5s. (both post free).

Varying Wall Thickness Tubing

" TAILOR-MADE TUBES " is a slogan of the Seefab Company of Sandviken, Sweden, which for the past 10 years has developed and launched on the market special cold-drawn steel and light metal tubes varying in wall thickness and diameter.

Light construction and uniform strength is one of the main advantages of the tubes manufactured according to " the 3 Seefab methods." This fact is among others recognised by aircraft builders for whom tubes with constant or varying outside diameter and tapered walls from one end to the other or along parts of its length have solved many problems, as for example when rotor spars are concerned. For the bicycle industry the Company has developed tubes with constant O.D., but with reinforced ends, which considerably reduce the weight of the frame yet permit modern electric welding methods to be used. Furthermore, tubes that have to be threaded at the ends can be reinforced there and be made with lighter gauge.

The Seefab methods, which have been patented in several countries, have attracted a keen interest also abroad and negotiations for licence rights are at present carried on with a number of foreign tube manufacturers.

Electrical Plant for the Metal Industries

IN a review of the activities of The English Electric Co., Ltd. during 1951, details are given of a number of interesting installations commissioned during the year. These represent collectively most types of rolling mill equipment, including drives for hot-reversing mills, tandem cold strip mills, temper mills, and numerous hot mill auxiliaries.

One of the outstanding contracts commissioned was a double-armature drive for a 46 in. blooming and slabbing mill in the new hot strip mill plant of the South African Iron and Steel Corporation. This drive is rated at 7,300 h.p. (R.M.S.) and 54/120 r.p.m., and was supplied complete with Ilgner set, control equipment and a considerable amount of main distribution switchgear, transformers and rectifiers. The large D.C. motor and its generators were duplicates of three other sets of equipment in the other works of the South African Iron and Steel Corporation. The motor was specially designed to permit its transportation by rail under the South African Railways' loading-gauge limits.

Twin drive for 45 in. slabbing mill recently commissioned in the Abbey Works of the Steel Company of Wales. The drive rating is 27,600 h.p. (peak), the speed 40/80 r.p.m., and the maximum torque 3,600,000 lb./ft.

Electrical plant for the new Abbey Works of the Steel Company of Wales, which will eventually contain three major rolling mills, was another important contract in hand. One of these mills, the 45 in. slabbing mill, has been in commission for over a year and has the first twin drive in the British steel industry, and the largest reversing drive in Britain. The peak h.p. rating is 27,600, the speed 40/80 r.p.m. and the maximum torque 3,600,000 lb. ft. Another of these large mills is the three-stand cold tandem mill which has recently been successfully commissioned. The mill is 80 in. wide and has a top speed of 2,000 ft./min.; strip up to 72 in. wide can be rolled at an average rate of about 3 tons a minute. The four D.C. motors are all double-armature units, three being rated at 4,000 h.p. and the reel motor at 1,000 h.p. at speeds of 85/221, 140/300, 170/360 r.p.m. respectively. There are two motor-generator sets with modern control systems associated with this mill.

The year 1951 saw the successful commissioning of the seventh 800 ft./min. cold strip mill for cold rolling (tempering) aluminium strip at a large aluminium works in Britain.

Equipments delivered but not yet commissioned include a 7,000 h.p. 50/120 r.p.m. hot reversing steel mill drive, the second of three ordered for Australia; a semi-continuous aluminium rod mill for South Wales, which has two A.C. motors for the roughing and intermediate stands, seven 150 h.p. D.C. motors for the continuous finishing train and a complete set of auxiliary drives and fittings; and a single-stand 1,000 f.p.m. cold mill for an aluminium works also in South Wales, which includes a 1,500 h.p. main motor and a 300 h.p. coiler motor.

Four 750 kVA saturable reactor and transformer equipments have been completed for supplying and controlling the re-flowing power on electrolytic strip tinning lines installed in South Wales.

Three hot reversing mill drives, two for overseas and one for home, with R.M.S. horse-power ratings from 2,350 to 8,000, were ordered, together with two Sendzimir mill equipments with all the auxiliary gear in one instance; also complete main drives for two cold single-stand strip mills overseas, aggregating 7,550 h.p. and covering mill motors, coiler motors and most of the auxiliary equipments, for steel strip rolling at speeds up to 1,650 f.p.m.

Auxiliary drives of all kinds have been ordered including those for two blooming and two structural mills abroad, two bloom shears abroad, corrugating lines, slitting lines, cutting-up lines and electrolytic cleaning lines.

Several equipments supplied by the Company are being modernised or extended, including power supply additions to two British hot strip mills. Both of these plants are to have rectifiers of 'English Electric' manufacture installed, totalling over 10,000 kW, to back up the output of the existing motor-generating sets. These, it is believed, will be the only examples in Europe of main mill plant fed from both generators and rectifiers.

"THE Industrial Diamond Trade Names Index for 1951–52" is now available and may be obtained from Industrial Distributors (Sales), Ltd., 32/34, Holborn Viaduct, London, E.C.1, price 3s. 6d.

NEWS AND ANNOUNCEMENTS

Canadian Trade Fair, 1952

THE Canadian International Trade Fair, which will be held for the fifth time in Toronto from June 2nd to 13th, 1952, is dedicated to the promotion of international trade by the Government of Canada, and its main objective, backed by an extensive advertising campaign throughout the world, is to provide an annual trading centre in Canada for manufacturers seeking home and overseas markets. Since the Fair was inaugurated in 1948, it has progressed to such an extent that it has now taken its place amongst the foremost annual trade fairs in the world. Exhibitors from 28 countries participated in the 1951 Fair, and whilst the largest group of buyers emanated from Canada, buyers from 53 countries registered their attendance.

From its inception the British participation has played a very important part, and for the past three years the United Kingdom has formed the largest group from any one individual country. Subsequent reports received from British exhibitors concerning their participation in the 1951 Canadian International Trade Fair gave every indication of their complete satisfaction with the successes attained, and, what is more important, they are in the Canadian Market to stay. In addition, many firms made valuable contacts and sales with other markets of the Americas.

In Canada at the present time commercial major development plans involving the expenditure of billions of dollars are in progress. As a result of this there is also rapid industrial expansion throughout the country. This, coupled with the extensive natural resources and cheap hydro power, is creating an ever increasing growth in sellers markets for capital and consumer goods as well as providing ample scope for British branch factories.

H. W. Gillett Memorial Lecture

THE American Society for Testing Materials has announced the establishment of an annual H. W. Gillett Memorial Lecture. The purpose of this lecture, which is being sponsored in co-operation with Battelle Memorial Institute, is to commemorate Horace W. Gillett, who was one of America's leading technologists, the first Director of Battelle in Columbus, Ohio, and an active worker for many years in A.S.T.M.

The memorial lecture will be delivered annually at a meeting of the Society, the first to be given at A.S.T.M.s 50th Anniversary Meeting in New York City during the week of June 23rd, 1952. The lecturer, who will be selected through a committee appointed by the A.S.T.M. Board of Directors, will cover a subject pertaining to the development, testing, evaluation, and application of metals. Dr. Gillett was intensely interested in these fields, perhaps particularly in a critical evaluation of metals and alloys. Further provisions in the agreement between the A.S.T.M. and the Institute provide for an honorarium, and the publication and dissemination of the lecture.

Dr. Gillett, in his accomplishments as scientist, engineer, metallurgist, scholar, and writer, in his work as Director of Battelle Memorial Institute, in his service to the American Society for Testing Materials, and by his qualities as a man, achieved a place of high honour and distinction among his fellow engineers and in the metallurgical industries. A member of A.S.T.M. for over 25 years, he served on many of its technical committees, notably in the field of metals, contributing numerous outstanding technical papers and reports to the A.S.T.M. publications. He was a most able writer and couched his material in a unique and effective style. Dr. Gillett, who died in March 1950, was an active member of many technical and scientific groups and had received numerous honours and awards.

Plant Maintenance Productivity Team

A SPECIALIST TEAM on Plant Maintenance left for America on the *Queen Mary* on December 31st, to spend six weeks in the United States studying methods and techniques in the field of Plant Engineering. The terms of reference of the team are as follows :—

(a) To study the organisation of American methods of industrial plant servicing and maintenance, with the object of securing maximum productivity.

(b) In particular, to study systems of planned preventive maintenance, with special reference to the statistical control used and to the degree of co-ordination between plant engineer and designer.

(c) To study American wage structures, bonus and incentive systems for maintenance work.

(d) To study safety precautions taken for maintenance personnel.

The composition of the team is : MR. J. R. STEVENSON, (*Team Leader*), Works Director, E.M.I. Factories, Ltd. ; MR. M. BROOKES, Chief Engineer, Lister & Co., Ltd. ; MR. C. E. HALTER, Plant Engineer in Charge of Refineries, National Oil Refineries, Ltd. ; MR. T. C. ROBINSON, Products Works, Imperial Chemical Industries, Ltd. ; MR. G. C. ALLFREY, Director of Royal Ordnance Factories, (Engineering), Ministry of Supply ; MR. F. G. HILTON, Consultant, Associated Industrial Consultants ; MR. W. J. CARRON, Executive Member, Amalgamated Engineering Union ; MR. E. STANLEY, Foreman Fitter, Reckitt & Colman, Ltd. ; MR. COLIN TROUP (*Secretary*), Editorial Director, John D. Troup, Ltd.

It is hoped that the Report of the team's visit will be published in the early autumn of 1952.

S.S.M.U.T.A. Midland Branch

THE Sheet and Strip Metal Users' Technical Association has recently formed a Midlands Branch to cater for the needs of its members in that area. The Branch will enable even closer liaison with the industry to be maintained, with resultant benefit to the study of problems attendant upon the use of sheet and strip metals. First Chairman of the Branch is MR. M. E. GUERMONT (Fisher & Ludlow, Ltd.) and Hon. Secretary is MR. E. N. SALMON (The Austin Motor Co., Ltd.). An

executive committee to administer the Branch has been formed as follows: Mr. W. Beresford (Fisher & Ludlow, Ltd.); Mr. E. Coupland (Rubery Owen & Co., Ltd.); Mr. L. Gibbs (Metal Sections, Ltd.); and Mr. G. G. Hoare (J. F. Ratcliff (Metals), Ltd.).

The first meeting of the Branch will be held at the Chamber of Commerce, New Street, Birmingham, on February 13th, 1952, and will take the form of a technical discussion forum on " Presswork and its Problems," at which a team of experts will be present to deal with questions that arise. Members who have agreed to serve on the expert panel are: Mr. T. Elkington (Peter Brasshouse, Ltd.); Mr. J. A. Grainger (A. C. Sphinx Spark Plug Co.); Mr. D. Lloyd (Fisher & Ludlow, Ltd.); Mr. S. Neville (Fisher & Ludlow, Ltd.); Mr. E. N. Salmon (The Austin Motor Co., Ltd.); and Mr. R. Snow (Edgar Vaughan & Co., Ltd.).

International Mechanical Engineering Congress

The Fourth International Mechanical Engineering Congress will be held in Stockholm June 4th–10th, 1952, when papers and discussions will be centred on improvements of materials used in engineering manufacture. This Congress is organised by the Trade Associations serving the mechanical engineering industry of twelve European countries.

Visits to the Works of Allmänna Svenska Elektriska AB (ASEA); AB Atlas Diesel; AB Scania-Vabis; Svenska AB Gasaccumulator (AGA); AB Svenska Metallverken; and Telefon AB L.M. Ericsson (all near Stockholm) have already been arranged during the Congress, and in the following week there will be an optional tour to the principal industrial centres of Sweden.

New College Engineering Library

At the College of Technology and Commerce, Leicester, a new Library for students (full-time, part-time and evening) in all branches of engineering is to be opened shortly in a building separate from the main college buildings. It is hoped to have a comprehensive collection of trade catalogues, instruction handbooks and house journals for use in this Library and the provision of such literature by firms connected with the industry would be greatly appreciated. It should be addressed to the Chief Librarian, College of Technology and Commerce, Lero Buildings, Painter Street, Leicester.

Secondary Light Metal Prices Rise

The Federation of Secondary Light Metal Smelters announces that, following the increases in the Ministry of Supply's prices for raw materials and in production costs, its members find it necessary to increase the maximum selling prices of the undermentioned alloys for deliveries on and after January 1st, 1952, as follows :—

Alloy	Old Price per ton	New Price per ton
L.M.1	£129	£157
L.M.2	£151	£175
L.M.4	£135	£163
L.M.6	£162	£186
Deoxidising Sticks (85/90)	£115	£143

Personal News

Mr. A. M. Kempson, Joint Managing Director of the Metals Division of Imperial Chemical Industries, Ltd., since 1945, retired at the end of 1951, after forty-four years with the Company and its constituents; he is succeeded by Dr. Maurice Cook, formerly Research Director of the Metals Division. The appointment to the Board of Mr. St. J. Elstub and Mr. G. A. D. Smith, is also announced.

Mr. J. S. Hampton has been appointed General Manager of Davy and United Roll Foundry, Ltd., Billingham; he has been a Director since 1945.

Mr. J. K. Ingram and Mr. W. J. Chadder have been appointed Directors of the Woodall-Duckham Vertical Retort and Oven Construction Co. (1920), Ltd. Both have been with the Company for more than thirty years.

Mr. W. W. Franklin, Chief Engineer of Davy and United Engineering Co., Ltd., has been appointed to the Board of the Company.

Col. H. C. Smith has succeeded Sir Edgar Sylvester as Chairman of The Gas Council. Col. Smith has been Deputy-Chairman since July 30th, 1948.

Mr. W. H. Platt, Assistant Sales Manager (Wrought Products) of The British Aluminium Co., Ltd., has retired after forty-one years' service in the Sales Division of the Company. Mr. C. F. Batstone will combine the functions of Principal Assistant Sales Manager with those previously carried out by Mr. Platt and will have the title, Assistant Sales Manager (Wrought Products); short title, A.S.M.(W.).

Dr. R. J. Anderson has left the Light Metals Division, National Production Authority, Washington, D.C., and has joined the South-west Research Institute, San Antonio, Texas.

Mr. G. B. Foote has resigned his position as Works Manager of Southern Forge, Ltd., to take up an appointment as General Manager of the Aluminium Industrial Development Co., Ltd., of Sydney, Australia, a recently formed company which will produce extrusions and tubes in aluminium and its alloys.

Mr. L. H. Collins has been appointed General Manager of General Metallurgical and Chemical, Ltd., and Mr. J. F. Widman has been appointed a Director of the Company and Manager—Chemicals Division.

Textile Machinery Makers, Ltd., Oldham, announce the appointment to the Board of Directors of Sir Cuthbert Barwick Clegg and Mr. George Hardman.

Mr. J. M. Brown, of James M. Brown, Ltd., has been elected Chairman of the Council of the Zinc Pigment Developments Association for 1952-53. The Deputy-Chairman will be Mr. J. F. E. Ruffell, of Durham Chemicals, Ltd. (Retiring Chairman) and Mr. H. L. Whitworth-Jones, of Imperial Smelting Corporation, Ltd. (Chairman-Designate).

Mr. J. R. Ratcliff, of K. and L. Steelfounders and Engineers, Ltd., has been elected to the Board as Engineering Works Director.

Mr. John Rae has retired from the Chairmanship of McKechnie Bros., Ltd., but is remaining on the Board, Mr. J. D. McKechnie, has been appointed Chairman of the Company but is also retaining the position of Managing Director.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

Safe A.C. Welding Rod Holder

THE many advantages of transformer type arc welding plant as compared with the equivalent direct current equipment are well known. One of the few disadvantages, however, is the increased risk of shock when using A.C. at the arc. Although normally this risk is small, in certain circumstances shock to the operator may have serious consequences. For example, when welding in confined spaces such as boilers or tanks the operator may be perspiring freely so that he is more vulnerable to shock. Again, when working at heights an unexpected shock, although slight in itself, might lead to a fall.

The provision of a completely insulated electrode holder obviates some of the risks. Such holders are often described as safety holders, but it must be realised that the main safety feature is lost when the electrode is inserted and thus becomes " alive." Many disagreeable burns and eye-flashes have occurred owing to arcing caused by the " live " electrode making accidental contact with earthed metal, particularly when work is being carried out in confined spaces.

Clearly the full solution to the problem can only be achieved by using an insulated holder and isolating the electrode from the supply when not in use. Several methods are possible, but the ideal solution must eliminate all risk of mistakes arising from the human element, and at the same time combine simplicity with reliability and low cost.

The General Electric Co., Ltd., has devoted considerable attention to this problem and has developed an insulated safety holder which has been specially designed for use with alternating current welding equipments and affords complete safety to the operator. It is made under British Patents Nos. 592004 and 593350, and embodies a simple switch in the handle whereby all exposed metal surfaces of the holder as well as the electrode itself are automatically isolated from the supply immediately the operator releases his grip on the holder.

It is capable of continuous welding duty at alternating currents up to 300 amperes and will accommodate electrodes up to 4 S.W.G. The isolating contacts are housed in the handle and are operated by depressing a lightly loaded spring lever located along the body of the holder as shown in Fig. 1. Although the welding current is usually broken at the arc, the switch may be called upon to perform this duty, so that it must be capable of

Fig. 2.—(W.6037).—Method of inserting an electrode into the holder.

breaking the full welding current without severe arcing at the contacts. Experience in service has established that it will interrupt this highly reactive current many hundreds of times without failure, and to accommodate such a switch within a handle of normal dimensions may be claimed as a considerable achievement in itself.

In order to prevent the safety feature from being deliberately put out of action by tying the operating lever in the " on " position, the design is such that electrodes can be inserted and withdrawn only when the switch is in the safety position. In order to replace an electrode, the central plunger, which holds it in position, must first be retracted by an outward movement of the switch lever as shown in Fig. 2, and this operation ensures that the contacts have separated and isolated the holder and electrode. Thus electrode replacements can be made quickly and in perfect safety.

Other advantages include cool operating conditions, even when working continuously at the maximum current ; long working life ; simplicity of dismantling without employing special tools, and ease of renewal of worn parts. In spite of the many special features of the new holder, it weighs only 24 oz., which is not excessive for its capacity, particularly in view of the excellent balance obtained by the use of a light alloy for the nose piece, while the pressure required to operate the switch lever is very small and cannot cause any fatigue to the operator.

The General Electron Co., Ltd., Kingsway, London, W.C.2,

Three-Roll Plate Bending Machine

FOR bending mild steel plate up to 10 ft. in width by ½ in. thickness, this three-roll bending machine made by the Bronx Engineering Co., Ltd., has rolls machined from solid steel forgings of 0·45 to 0·50% carbon steel of the highest elongation. The top roll is 12 in. dia., bottom rolls 10 in. dia., all with a body length of 10 ft. 4 in. Bottom rolls have grooves machined in the periphery to assist in gripping the plate.

The housings are of cast iron heavy cored box section. The lower part of the housings contains the worm gearing for adjusting the top roll, and is provided with covers forming an oil-tight case so that the gearing runs immersed in oil. The top roll is mounted in bearings of

Fig. 1.—(W.5879).—G.E.C. Safety type A.C. electrode holder with the insulating tube withdrawn to expose the isolating switch.

cast steel lined with phosphor bronze. Both are pivoted to the upper ends of the adjusting screws to allow the end bearing to be swung down for removing cylinders, and also to permit the top roll to be operated in a tilted position for conical rolling. The bottom rolls work in phosphor-bronze lined bearings with loose caps. The rolls are mounted on a fabricated steel baseplate, enabling the housings to be maintained in perfect alignment. At the driving end, all gear drives, motor and controls are mounted on a substantial cast iron bed plate which is securely bolted to the main bed.

All gearing is totally enclosed in an oil-tight cast iron gearbox, the gears throughout being of solid steel with machine-cut helical teeth. The bearings are phosphor bronze lined except the high-speed shaft connecting to the motor, which is mounted in ball and roller bearings. The gearbox is driven through a flexible coupling from a 16 h.p. motor arranged for reversing by suitable hand-operated control gear.

Top roll adjustment is carried out by means of worm gearing located in the main housings, the main driving shaft coupling the worms in the housings being directly connected to a totally enclosed gear reduction which in turn is driven from an 8 h.p. motor. The gears in this box are of the double helical type, all machine-cut from solid steel blanks, and their shafts are mounted in roller bearings. The motor is arranged for reversing by means of hand-operated control gear. To permit the tilting of the top roll a separate clutch is fitted in the driving shaft ; this disengages the worm gearing at the end. An indicator with a large enamel dial is fitted, showing the position of both ends of top roll at any time. An extension is provided on the top roll to counterbalance the weight when swinging down the end bearing. This support engages the ball end of the roll, and is operated with a handwheel, spiral gears and screws.

The Bronx Engineering Co., Ltd., Dudley Road, Lye Stourbridge, Worcs.

The Rotary Draw Former

THIS tool, developed by the Cyril Bath Machining Company from experience with the Bath Universal Contour Former, has proved particularly useful in stretch-forming Haynes–Stellite, and various other alloys used in the afterburners and combustion chambers of jet engines. It can also produce a number of other jet engine parts which have not been readily produced by other methods.

The Rotary Draw Former consists of a power-driven rotary steel table, similar to a vertical boring mill, and a horizontal bed on which is mounted a hydraulically movable carriage. On the carriage is mounted a swivelling ram, like a large shaper, operated by a hydraulic cylinder, and the whole element mounted on roller bearings.

On the ram is adjustably mounted one of two stretch jaws. The other jaw is mounted on the rotating table and the work is stretched between them. The work is previously shaped roughly to the required cross section, as are also the gripping jaws. The metal is then stretched between the jaws, and this pressure is automatically held constant during the forming operation. The table is then revolved, and this causes the metal to be stretched or drawn over the outer diameters of the

shape mounted upon the table, the amount of draw becoming progressively less toward the inner diameter where very little elongation may be required. Simultaneously, to assist the process and to assure accuracy in cross section, a side head applies hydraulic pressure through a hard bronze shoe, wiping the metal on to the revolving die as the table revolves.

Rings up to 48 in. in diameter have been drawn with a ten-thousandths tolerance for variation in cross section or circumference. In the final operation the rings are held in a welding fixture and automatically welded with atomic hydrogen, the cooling being so rapid that distortion in the finished ring is held to a minimum. No re-stretch operation is required and, indeed, in these tough metals restretching is seldom satisfactory.

The Rotary Draw Former will produce equally well elliptical or rectangular shapes. Where complete circular or closed shapes are required, the work is drawn on a spiral die and the ends are sprung together for the final welding operation.

The same machine will also produce long sweeping open curved shapes, shapes containing reverse bends, or curves in two planes. It will form aluminium or bronze, and alloy extrusions, and will vary the angularity of the extrusion, as in wing attach angles or tank straps, while forming the work. It will also form round, square, or other hollow tube shapes, and sheets of all sorts and sizes can be handled by changing to suitable jaws. It will work equally well in the toughest steels, or in very light aluminium extrusions, the latter by reason of the hydraulically balanced ram and the roller-mounted stretch ram and cylinder, which respond to very slight pressures or resistance.

The dies in use for rotary work consist of a turned cast iron base on which is mounted a strip of steel so shaped as to give the required cross section. This ring is either turned up to size and split, and welded in place spirally, or it is planed and one end welded to the die. The Rotary Draw Former ram then wipes the steel bar spirally around the cast iron base and it is so welded into position.

Dies so made cost much less to produce than press dies and will make shapes virtually unobtainable by any other means. The metal, pre-stretched and applied to the die while in this condition, gives a very good product in the very tough materials needed in jet engine manufacture, and at a minimum cost and loss from scrap.

The machine is produced in six sizes : 12½-ton, 25-ton, 35-ton, 50-ton, 75-ton and 100-ton. They are on order by most manufacturers of jet engine parts. The Cyril Bath Company's standard Contour Former can be converted to a Rotary Draw Former by the addition of appropriately designed self-contained supplementary parts.

Cyril Bath Machinery Company, 6984 Machinery Street, Cleveland, Ohio, U.S.A.

North America Visit

DR. K. STRAUSS, Technical Director of Foundry Services, Ltd., recently returned to this country after a two-months visit to North America. As well as visiting a number of foundries, Dr. Strauss concluded arrangements in connection with the setting up of a new factory and laboratory at Guelph, near Toronto.

CURRENT LITERATURE

Book Reviews

Chemical Analysis of Cast Iron and Foundry Materials

By W. Westwood and A. Mayer. Edited by J. G. Pearce, Director of B.C.I.R.A. Published by George Allen and Unwin, Ltd., London 1951 ; 565 pp.; 30 illus. Price 42s. net.

SMOOTH landings express more of a pilot's skill than does ordinary flying. The realistic down-to-earth textbook is a vastly greater achievement than the all-too-plentiful cloudy and evasive treatise. Even better is the achievement when the practical is combined with originality.

In their " Chemical Analysis of Cast Iron and Foundry Materials," W. Westwood, Head of the Chemical Research section of the British Cast Iron Research Association, and his former colleague, A. Mayer, have avoided the impracticable as the plague and have given us this country's first commercially published book on ferrous analysis to deal primarily with cast iron and iron foundry materials. The authors have taken full advantage of the exceptional facilities at the B.C.I.R.A. Further, through their active membership of official committees on analysis, they have been singularly *au fait* with organized method development.

Year after year, world-wide analytical research continues to unfold a bewildering variety of new methods. It has been the task of the authors closely to investigate those developments in ferrous analysis and, aided by their own bench research, to consolidate them into reliable and rapid technique. In this way they have drawn the threads of scattered researches into a concise and rational design, so creating a volume suitable even for junior practising staff.

A description of relevant bench technique is followed by the main section, occupying almost half the volume and dealing with the determination of 25 cast iron constituents. Arranged alphabetically for ready reference, these include antimony, bismuth, cerium, lead, selenium, tellurium, and zirconium. In the 60 or so proved methods, gravimetric, volumetric and colorimetric techniques are represented equally, so deep has been the recent impress of colorimetric procedure.

This section reflects the demand for rapidity. Indeed, one method for silicon occupies a mere 10–14 minutes. Much attention has been paid to the prevention of interference, even by the occasional elements. The few sources of interference overlooked are of minor significance ; they include, apparently, that of zirconium with Method I for aluminium, that of cerium, selenium and tellurium with Method I for chromium, that of selenium and tellurium with Method I for manganese and that of boron with Methods I, II and II for silicon. In certain methods it is assumed that the qualitative composition is known. Notes appended to each method describe modifications imposed by the presence of occasional elements and afford other guidance ; these Notes should be perused before the methods are applied.

The direct cyanide-oxine method for aluminium referred to on page 49 is altogether satisfactory provided manganese is first removed as dioxide or ferrocyanide and the coagulation of very small contents is induced by a known volume of standard aluminium solution. In the dimethyl-glyoxime precipitation (p. 180) of nickel it is advisable to allow to stand until a temperature of 20–25° C. is reached, and to use wash water at this temperature. Sodium pyrophosphate is an advantageous inhibitor of iron hydrolysis, in that no intense coloration develops.

An admirable feature is an appraisal of available gravimetric, volumetric and colorimetric methods for each constituent. For each selected method the principle, reagents, duration, reproducibility and theory are clearly stated. The strength of the text is augmented by references to original sources.

Subsequent sections deal in laudable detail with the analysis of 21 addition alloys (120 pages), iron ores, slags, refractories, coke, coal dust and sand-binding oil. The treatment is of a very high standard, and composite schemes are exploited for these materials. In the volumetric determination of cerium in " mischmetall " (p. 403) the permanganate formed from the manganese content may be reduced, preferably in the presence of phosphoric acid, by means of dilute hydrochloric acid ; cerate suffers no reduction.

Throughout the volume each section is prefaced with correct sampling procedure, an influential preliminary to which the authors rightly attach much importance. In the interests of completeness, 12 useful appendices deal with pyrometry, compositions, available standards, literature and constants. The volume is well produced with a clear and pleasing format. Conveniently, almost all the illustrations are line drawings embodied in the text.

This authoritative textbook raises the analytical chemistry of cast iron and foundry materials to a new level and absolves even the experienced ferrous analyst from so much perplexity that its wide approval as an effective aid to foundry efficiency is assured.

E.C.P.

Surface Defects in Ingots and their Products—Recommended Definitions

Prepared by the Ingot Surface Defects Sub-Committee (Steelmaking Division) of the British Iron and Steel Research Association, and published by the Iron and Steel Institute, London, November, 1951. 51 pp., 105 illustrations. 25s. net (15s. to Members of the Institute).

WHEN the Sub-Committee responsible for the preparation of this book was first set up, its terms of reference were : " To examine data on, and to investigate the causes of, ingot surface defects and their influence on the semi-finished and finished product." During the course of the work, it became obvious that there was need for standardisation of terms. Often a particular defect was known by a number of names, and conversely, one name was sometimes applied to more than one type of defect. With the object of reducing the confusion arising from this state of affairs, the Sub-Committee has prepared a well illustrated volume dealing with the various defects likely to be encountered.

The volume is divided into three parts, the first dealing with defects present in the ingot, while Parts II

and III deal with semi-finished and finished products respectively. After careful consideration, the Sub-Committee has chosen in each case what it considers to be the most apt terms and recommends that these terms be generally accepted. Defects which are peculiar to the manufacture of steel sheet, strip, and wire are not included as it is considered that their more specialised nature warrants separate attention. This book will be of immense value, not only to all steelmakers who want to ensure that discussion of the subject is not made valueless by lack of definition, but also to those concerned with the industry's products, such as re-rollers, bright drawers and shipbuilders.

Trade Publications

WE have received from Foundry Services Ltd., Long Acre, Nechells, Birmingham, 7, copies of three of the series of information sheets giving helpful hints on a wide variety of foundry topics. Two, Nos. 14 and 48, are revised issues dealing with High Tensile Brass Alloys and Nodular Cast Iron respectively. The third No. 49, is a new edition sheet dealing with Malleable Cast Iron. No. 14 gives general data concerning chemical composition, moulding, melting, metal treatment, etc., of the alloys usually referred to as manganese-bronze, while the two main processes for the production of nodular cast iron—that developed by the British Cast Iron Research Association in which additions of cerium are used, and the Mond Nickel and International Nickel Companies' process in which magnesium is used as the nodularising agent—are treated in No. 48. The salient features of each process are given, and reference is made to results obtained in practice. In the Malleable Cast Iron information sheet, the essential features of whiteheart and blackheart castings are discussed, together with an outline of the processes involved in their production (including gaseous annealing) and some of the defects encountered.

IN the belief that it is more practical to know how to get information than to store it for future use, Sunvic Controls, Ltd., intends to issue a News-sheet from time to time. The first of these appeared recently and contains brief details of new products, together with a review of the standard range which includes references to descriptive leaflets. Readers who are anxious to receive copies of the News-sheet should get in touch with the Company at 132–135, Long Acre, London. W.C.2.

THE latest Alar Data Sheet is entitled " Colour scheme for the Identification of Aluminium Casting Alloys." It is not intended as an attempt to popularise the use of a colour scheme as distinct from other methods of identification, the aim being to avoid the confusion which has been possible as a result of lack of uniformity in colour coding. Copies may be obtained from Alar, Ltd., 3, Albemarle Street, London, W. 1.

BIRLEC Publications 78 & 79, the first of a series describing all types of the Company's induction heating equipment, deal with surface hardening and localised heat treatment applications, respectively. The Birlec approach to each problem is to consider the heat-treatment unit as a machine tool, incorporating the same characteristics and achieving the same advantages as the other units in the mass production line with which it is

associated. For each series of applications, motor-alternator, valve-oscillator, or spark-gap convertor generating equipment can be provided, depending on the high frequency output required. Copies of these illustrated leaflets may be obtained from Birlec, Ltd, Tyburn Road, Birmingham, 24.

AN illustrated leaflet dealing with the range of melting furnaces made by the company has been issued recently by Wild-Barfield Electric Furnaces, Ltd., Watford, Herts. These include low-temperature nickel-chromium wound furnaces for use up to 650° C. and 800° C., and high-temperature furnaces, with recrystallised carborundum heating elements, suitable for temperatures up to 1,300° C.

WITH the increased application of resistance welding, and the high duty performances required of various types of electrical apparatus, there has been an increasing demand for materials with good mechanical properties (both at normal and elevated temperatures) combined with relatively high electrical conductivity. The fullest particulars of the properties, including machinability, of the range of such alloys made by Enfield Rolling Mills, Ltd., are set out in a recently published booklet. Copies may be obtained from Enfield Rolling Mills, Ltd., Brimsdown, Middlesex ; applications should be on firm's headed notepaper.

Books Received

" STEELS in Modern Industry."—A Comprehensive Survey by 29 Specialist Contributors. General Editor : W. E. Benbow (Editor, " Iron and Steel "). 562 pp., with 260 illustrations. London, 1951. Iliffe & Sons, Ltd. 42/- net (postage 11d.).

" Phase Transformations in Solids." Symposium held at Cornell University, August 23rd–26th, 1948. Editorial Committee : R. Smoluchowski, J. E. Mayer and W. A. Weyl. Sponsored by The Committee on Solids, Division of Physical Sciences, The National Research Council. Foreword by Lloyd P. Smith. 660 pp. New York and London, 1951. John Wiley & Sons Inc., and Chapman & Hall, Ltd. $9·50 or 76/- net.

" The Welding of Non-Ferrous Metals," by E. G. West, Ph.D., B.Sc., F.I.M., F.R.S.A. Foreword by Leslie Aitchison, M.Sc., D.Met., F.R.I.C., F.R.Ae.S. 553 pp., inc. numerous references and indices. London, 1951. Chapman & Hall, Ltd. 55/- net.

" Mechanical World Year Book." 1952. 360 pp., numerous tables. Manchester, 1951. Emmott & Co., Ltd. 3/6d. net.

" The Electrical Year Book." 1952. 360 pp., numerous tables. Manchester, 1951. Emmott & Co., Ltd. 3/- net.

" Schnellstähle und ihre Warmebehandlung," by Dr.-Ing. Willi Haufe. 276 pp., inc. 258 illustrations and numerous references. München, 1951. Carl Hanser Verlag. 29.-DM.

" Leaves of Gold " (a history of goldbeating). Designed and produced for George M. Whiley, Ltd., by Newman Neame, Ltd. Drawings by John Minton ; text prepared in collaboration with Cecil Whiley by H. L. Hunter. 71 pp., including bibliography. London, 1951. Limited Private Edition.

The Basic Types of Phosphate Coatings and Where to Use Them

By Robert F. Ayres

PHOSPHATE coatings are applied to iron, steel, zinc, cadmium and aluminium by spraying, dipping or painting the surface of the metal with solutions of acid phosphates so that a protective layer of phosphate crystals is formed on the surface. The solutions used, the exact composition of the coating, its thickness, and the methods of treatment differ widely according to the applications for which the coated metal is intended and the patented process used.

The cleaning of metals by solutions based on phosphoric acid should be clearly differentiated from true phosphate coating treatments. The cleaning solutions consist essentially of phosphoric acid, organic grease solvents and surface active agents. The purpose is to remove rust and grease from the metal in one treatment, leaving a slight surface etch to promote mechanical bonding with paint, plus a thin phosphate residue which gives some resistance to corrosion. The phosphoric acid concentrations used and the quality of the detergent constituents usually ensure the removal of oxides, dirt and grease, but the acidity of these cleaning solutions is necessarily too great to permit the build-up of any substantial crystalline phosphate coating on the metal. The big difference between phosphoric acid cleaning and acid phosphate coating lies in the low pH maintained in the cleaning solutions.

The important functions of phosphate coatings are :

(1) The insulating properties tend to suppress electrochemical corrosion under a paint film, restricting attack to the site of any damage.

(2) The physical form of the phosphate layer serves to key an organic finish to the surface.

(3) An actual chemical bond is formed between paint and surface.

(4) The absorptive characteristics of phosphate coatings and their affinity for oils and lubricants lead to corrosion resistance and reduced wear.

There are five main types of commercial phosphate coatings. These consist of the phosphates of manganese and iron ; zinc and iron ; zinc ; aluminium and chromium ; and iron. The characteristics of each of these types, such as thickness, crystalline structure and chemical composition, depend on the method of cleaning before treatment, the system for applying the phosphating solution, the duration of the treatment, and the composition of the bath. Choice of the type of material to be used and the method of application depends on the metal to be treated and the purpose the coating is to serve.

Manganese-Iron Phosphates. These are heavy coatings ranging from 1,000 to 4,000 mg./sq. ft. in weight. They are used principally to improve lubricating properties on friction surfaces of iron and steel. Application is by immersion methods and requires a time of treatment from 10 to 30 minutes. The lubricating assistance which these coatings give is due both to the fact that they form parting layers and to their high absorptive affinity for lubricants. Pistons, piston rings, cylinder liners, connecting rods, crankshafts, gears, valves, bearings, etc., carry uniform oil films over their entire surfaces because of the presence of the phosphate coatings, and the dangers of metal-to-metal contact are greatly reduced or eliminated. The coatings also reduce running-in time, for the same reasons. The same coatings are also frequently used as carriers of oil to retard corrosion on surfaces where friction is no problem.

Zinc-Iron Phosphates. There are several different kinds of zinc-iron phosphate coatings. Each type is designed to form a surface for oiling to prevent corrosion, to function as an aid to cold working, or to provide a paint base.

Coatings ranging in weight from 1,000 to 4,000 mg./sq. ft. are applied to iron and steel, and subsequently oiled to prevent rust. Nuts, bolts, and screws are typical of the kind of work processed, but larger parts are frequently treated in the same manner.

These coatings are commonly applied by 20- to 30-minute immersion, but spray application is occasionally used.

Coating weights in the range between 150 and 3,000 mg./sq. ft. are employed to improve the cold working of metals ; the coating also increases the life of the die and reduces power requirements. Coatings weighing between 100 and 600 mg./sq. ft. are widely used as surface treatment for iron and steel before painting. Application can be by brush, dip, or spray methods. By modifications in the solutions, the same material can sometimes be applied to zinc, cadmium, and aluminium, and frequently several of these metals are processed through the same machine.

Zinc Phosphate. This type of coating is produced on zinc and cadmium surfaces as a base for paint. The coating weight runs from 75–200 mg./sq. ft. and the surface has a medium to dark grey appearance. Galvanised steel, zinc-base die castings, electrodeposited zinc or cadmium parts are examples of work that may benefit from this treatment. Immersion or spray application accomplishes the purpose in two minutes or less.

Aluminium-Chromic Phosphates. In addition to the treatment of aluminium with modified solutions of the zinc-iron type to form a grey crystalline layer on the surface, there are processes which produce amorphous coatings composed of aluminium and chromic phosphates. Coating weights run from 20–200 mg./sq. ft. and application can be by brush, immersion or spray, with treatment times ranging from 20 seconds to 5 minutes. These coatings are usually preparations for painting, but they are sometimes used unpainted to increase corrosion resistance.

Iron Phosphates. Thin, hard, highly continuous coatings for metals have come into increasing use in the last decade. In addition to their paint bonding and corrosion inhibiting properties, the economy and ease of their use enhances their value in industry. Fewer steps are required because one solution usually performs both the cleaning and coating operation, maintenance and control of the bath is relatively simple, acid proof equipment is not required, and the problem of heavy sludge accumulation is absent.

These coatings, while composed primarily of iron phosphates when

formed on iron and steel, must include also a certain proportion of other insoluble heavy metal oxides or phosphates if the coatings are to achieve their maximum protective value. Provision for such supplementary deposits can be incorporated in the formulae, along with proper oxidising agents and/or activators.

On non-ferrous metals, this type of bath usually requires certain modifications to produce visible films, but even with no obvious surface change, experience has shown that the treatment leads to improved results in paint adhesion and corrosion resistance. The best method of application is by pressure spray washer, although tank immersion is frequently employed. Treatment time runs from 1–5 minutes.

Continuous Heat Treatment of Aluminium Alloy Strip

By M. Lamourdedieu

THE problem of the continuous heat treatment of Duralumin 24S, 24S Alclad and 17S alloy strip remains rather acute since the development of tandem rolling mills for rolling long coils of wide strip. This paper describes the promising results of tests by the Société Centrale des Alliages Legers. Preliminary tests indicated that the time necessary to dissolve the microconstituents varied with the amount of cold reduction. For 1·0 mm. (0·040 in.) sheets of a Duralumin alloy cold rolled 700%, a tensile strength of 58,400 lb./sq. in. was secured after 1 min. heating ; whereas 3 min. was required to develop the same strength in sheets not cold rolled. The minimum rate of quench was also studied. From these various tests it was concluded that the continuous heat treatment of aluminium alloy strip of the Duralumin type is possible under the following conditions : time at temperature : 2 min. for 1·0 mm. (0·158 in.) sheet, with a subsequent minimum rate of passage through the water spray quench of 1·50 m./min. (about 5 ft./min.).

Transverse electric induction heating of the strip—a method developed by the United Engineering and Foundry Co., New Castle, Pennsylvania, for steel strip in connection with continuous tin plating—was decided upon for the continuous heat treating furnace. A pilot furnace large enough for aluminium strip up to 56 in. wide and 0·010–0·080 in. thick was set up at the New Castle, Pa, plant of the United Engineering and Foundry Co. The speed is a function of the thickness and may be as high as 50 ft./min. (15

m./min.). The continuous heat treatment furnace is preceded by a reel for holding the coil, felt wipers, shears, a welder and a loop pit with tension rolls on either side. The strip is heated to the approximate heat-treatment temperature by an induction coil giving a transverse flux of 1,875 kVA, single phase, 60 cycles, 440 volts. A battery of condensers of 1,950 kVA, 575 volts, 60 cycles, single phase, paralleling the induction core, correct for power factor. This requires less than a minute. Next the strip passes into a stabilizing furnace in which the proper temperature is maintained. This stabilizing furnace is electrically heated and the atmosphere is continuously circulated in order to bring the strip up to the exact solution heat treating temperature in a uniform manner, and to achieve this temperature as quickly as possible. Edge protectors avoid overheating the edge of the strip. On leaving the furnace, a strip is quenched by water sprays and dried with a warm air dryer. A loop pit, leveller, shears and recoiler complete the line. In pilot tests good properties were obtained at a speed of 19 ft./min., and although a throughput of 30 ft./min. gave poor results, it is hoped that a speed of 19 ft./min. is not the maximum possible. The furnace has been shipped to France but not yet put into action.

Separation of Metals from Mixed Amalgams

TO overcome the special difficulties of isolating the pure metals from amalgams containing more than two components, a new process is put forward which is based upon the development of a large difference in the electrochemical potentials of the constituents and thus ensures that one of the metals is retained in the amalgam form while the other goes into solution as a salt and can be subsequently crystallised out. Successful treatment calls for the development of a potential difference of 200–250 mV in the case of ions with multiple valencies. The desired potential difference can be developed with the aid of complex-forming solutions or with alkaline solutions, suitable reagents being potassium cyanide or ammonia with or without the addition of an amine, and solutions of citric or tartaric acid. The treatment is combined with the reaction of the amalgam with a decomposing agent such as chlorine, oxygen, hydrogen peroxide, mercuric chloride, or mercuric oxide. Preliminary trials with different complex-forming agents are desirable in order to establish which imparts the highest potential difference with a given amalgam. This is most rapidly performed by measurements of the polarographic half-potentials.

In the case of a thallium-cadmium mixed amalgam containing 3·5% Cd and 3% Tl, the following procedure is recommended : 10 kg of the amalgam are reacted with a solution containing 110 g. ammonium hydroxide and 100 g. ammonium carbonate per litre, while 500 ml. of 30% hydrogen peroxide are stirred in. There is formed a solution of pure cadmium carbonate (Tl content less than 0·001%). The mass is then covered with 1·3 litres water, 450 ml. nitric acid (S.G. 1·4) are added, and stirring is continued at 90° C. until the acid reaction disappears. Thallium nitrate crystallises out on cooling, while the cadmium remains in solution or remains amalgamated.

The polarographic half-potential (measured against the normal calomel electrode) of the solution in the absence of the complex was 0·63 V. for cadmium and 0·51v for thallium, whereas in the treated solution the values were respectively 0·86 V. and 0·52 V.

A Further Note on the Reproducibility of Analytical Results

By E. C. Mills, A.R.I.C. and S. E. Hermon

Research Laboratories, High Duty Alloys, Ltd.

*In this further contribution on the subject of reproducibility of results in analytical work,
an interesting comparison is drawn between the variations occurring in research analysis
and those obtaining in routine analysis.*

HAVING constructed certain curves showing the relationship between coefficient of variation and mean content of a number of elements in aluminium and magnesium alloys,[1] it was thought useful to plot similar curves for results derived from special and research analyses of a somewhat wider selection of materials met with in our laboratory. The object was to compare these graphs with those already obtained and, if possible, establish a relationship between them. We wish to emphasise that the data described below is from one laboratory only.

Our research records, for a period of three years, were studied. The data presented cover 22 different elements encountered in the course of analysis of the following materials :

Group I	Aluminium alloys.
	Magnesium alloys.
	Cast irons.
	Mild and alloy steels.
Group II	Aluminium bronzes.
	Nickel-base alloys.
	Fusible alloys (bismuth base).
	Ferro-alloys.

The majority of the determinations come within Group I.

The results under consideration were obtained by selected volumetric, gravimetric, photometric and polarographic procedures, not including those normally used for routine control. No spectrographic results are included because we rarely use spectrographic procedures for research analysis.

The coefficients of variation of the various elements were calculated from replicate determinations, and in no case were results accepted for evaluation where there were less than five in number. Points were plotted as before showing the coefficient of variation against mean content. Initially, only points derived from 10 or more determinations were plotted ; points derived from lesser numbers of determinations were added later.

With a few exceptions it was found that the coefficients all fell around a single smooth curve similar in shape to

1 Hermon, S. E. and Mills, E. C., *Metallurgia*, 1950, **42**, 220.
2 Scheuer, E. and Smith, F. H., *Metallurgia*, 1949, **41**, 44.
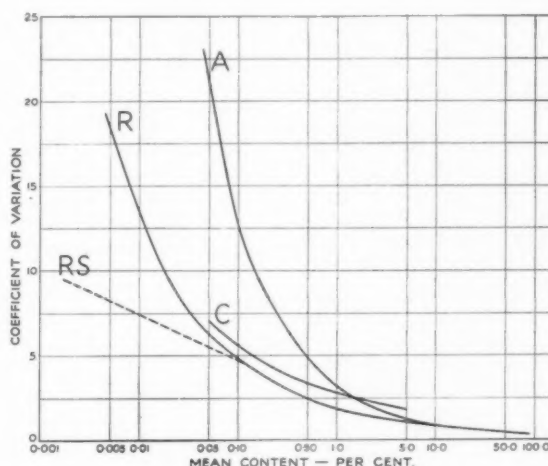
that obtained by Scheuer and Smith,[2] but showing a higher order of reproducibility, particularly in the lower content regions. This new curve is reproduced here as curve R, together with our original curves A and C derived from classical methods, and photometric and polarographic methods, respectively.

As control methods are usually a compromise between accuracy and speed, and those of research usually chosen for their accuracy, irrespective of the time taken, the higher precision shown by graph R was expected. Apart from this, several other points of interest are evident. In contrast with the two distinct curves A and C observed in control work the majority of points derived from the research photometric, polarographic, volumetric and gravimetric procedures fall around the *single* smooth curve R.

Within the range 0·05–1·0% the marked difference between A and C and the close proximity of C to R is of particular interest. This demonstrates how, within the range quoted, the precision of our routine control photometric and polarographic analysis is better than that obtained by routine classical analysis, and is brought very close to that for research analysis using high accuracy methods and employing skilled analysts. One

TABLE I.—EXAMPLES OF RESULTS FALLING IN THE REGION OF RS

Alloy	Element	Sample Weight g.	Mean Content %	Number of Determinations	Coefficient of Variation
Pure magnesium ..	Copper	5	0·0041	22 *	7·2
Pure magnesium ..	Nickel	5	0·0022	20	8·4
Aluminium	Titanium	1	0·079	10	2·95
Steel	Sulphur	5	0·043	18	4·36
Steel	Sulphur	5	0·041	9	4·84

or more of the following reasons may account for this.

Our particular routine photometric methods were chosen for their extreme simplicity and ease of mastery by semi-skilled assistants.

The calibration and reproducibility of the routine instruments are frequently checked by members of the research staff. Female staff using photometric methods are changed very infrequently, whereas male staff engaged on gravimetric methods are continually being changed.

Gravimetric methods are only used where relatively simple photometric or polarographic procedures are not available, and where spectrographic methods are not readily applicable. Consequently the elements determined gravimetrically are the more difficult ones and greater experience is required for their successful application.

For the efficient analytical control of foundry production melts, it is desirable that the analysis be carried out within a predetermined time of taking the sample, and that results for all the different elements be made available at approximately the same time. Because of this requirement, the time allowed to complete the relatively complicated gravimetric determinations is approximately the same as that allowed for similar sized batches by the simple photometric and polarographic methods. This obviously gives a greater advantage to the personnel using the latter methods.

On the other hand, conditions appertaining to research analysis are entirely different. The analysts, after having considerable experience on routine processes, are given further specialised training until they become equally proficient with any type of method. They normally remain on this type of work. No time limit is usually set for any analysis and the size of the batches is much smaller—e.g., 3–8 samples as compared with 20–40 on routine foundry control.

In considering A and R we see that for contents between 5 and 15% (approximately), only slightly better reproducibility is obtained by research analysts using refined methods compared with assistants using routine classical methods. For control purposes, relatively complicated procedures for the concentration and separation of these larger percentages of alloying elements from the base elements are not necessary and the advantage gained by these refinements, in many cases, does not appear to justify their use.

As mentioned above, we find a few exceptions to the general trend of curve R. These occur in the concentration range from 0·1% downwards, and we note that these coefficients of variation were derived from elements which had been determined photometrically, either after a relatively simple chemical processing, or after concentration and isolation of the required element from most of the base metal by a simple macro-separation. The values fall fairly uniformly below R, approximately in the region of the dotted line RS ; some typical coefficients are given in Table I. Also included in the table are two

examples of coefficients of variation obtained from sulphur on steels by the ordinary gravimetric method (5 g. sample weight). The relatively favourable position of these results is in agreement with those reported by van Someren,[3] who obtained coefficients of variation of from 3–6 (approximately) for 0·07–0·03% sulphur.

Very few phosphorus determinations on steel have been carried out, but results obtained indicate that better reproducibility is possible than shown by the curve R.

From the position of RS, subsidiary to the curve R, it would seem to correspond to the photometric and polarographic curve C for routine analysis.

In the above findings, there seems to be practical evidence for a commonly held opinion that, where photometric and polarographic procedures are carefully selected and correctly applied to routine control analysis, considerably better reproducibility can be obtained than with classical methods.

It is also evident that where every precaution is taken to get the best results possible, the general shape of the coefficient of variation versus concentration curve appears very similar to that obtained from results of ordinary control analyses, except that the former curve shows an expected higher order of precision, below an element concentration of about 5%.

It would be interesting to see if reproducibilities obtained using micro-chemical procedures were similar to those already considered and where low concentrations are involved the types of curve obtained using radioactive tracer, or other physical methods (e.g., vacuum fusion) would be very informative.

By obtaining sufficient evidence over a wider field, and after suitable correlation, it might be possible to obtain a curve or series of curves of universal application which would provide a guide to the relative analytical reproducibilities expected in, and the probable limitations of, any particular laboratory.

The authors wish to thank the Directors of High Duty Alloys, Ltd., for permission to publish this note.

3 van Someren, E. H. S., *Metallurgia*, 1950, **42**, 52.

The Physical Society Exhibition

THE Physical Society's 36th Annual Exhibition of Scientific Instruments and Apparatus will be held from Thursday, April 3rd to Tuesday, April 8th, 1952, excluding Sunday. As in 1951, the Exhibition will be located in both the Royal College of Science main building, Imperial Institute Road, and the Huxley Building, Exhibition Road, a representative selection being exhibited in each building. Tickets will be valid for entry into both buildings : on Thursday morning and afternoon, April 3rd, the Exhibition will be open to Members of the Society and Press only.

Present circumstances, both national and international, render the exhibition of great interest to all users of instruments. The rearmament programme has caused a great resurgence of interest in a wide range of equipment for service use, and continued need for higher productivity and increased exports has led to ever increasing developments in the field of industrial instruments.

The Exhibition Handbook containing the description of exhibits will be available from the Physical Society early in March, price 7s. 3d. including postage.

Speedier Powder Quality Control Made Possible

New Photoelectric Equipment Described

One of the most important characteristics affecting the quality of a powder is the particle size distribution and its determination is essential if effective control is to be exercised. The instrument described in this article has been designed with the object of putting sub-sieve analysis on a practical routine basis.

PROCESSES employing powdered material rely for their satisfactory operation on a consistent quality of powder, one of the important characteristics affecting the quality of powders being the particle size distribution. In cases where a significant proportion of the material is finer than the finest sieves (300–400 mesh), indirect methods of measuring the fineness have to be employed.

Microscopic counting of powder particles can be a very tedious operation and the results may be biased by the technique of the operator, whilst methods of sub-sieve particle size analysis which rely on the separation of the sample into definite fractions by elutriation, are, in general, much too time-consuming to be of service to a production control laboratory, and are reserved for the more exacting requirements of the research worker, who may wish to study the individual properties of the various particle size fractions he obtains. Bound Brook Bearings (G.B.), Ltd., in common with other firms engaged in powder metallurgy, found themselves seriously handicapped in controlling the quality of their products because of the lack of suitable measuring instruments for sub-sieve powder fineness. It was decided, therefore, to tackle the development of suitable equipment.

The demand was for an instrument capable of handling upwards of ten samples a day, and requiring the minimum of skilled attention. A survey of the work already done in this field indicated that an improved form of sedimentation apparatus was likely to satisfy the requirements. The use of a compensating optical system enabled the sedimentation to be measured photo-electrically without encountering the difficulties associated with maintaining a constant standard of illumination. Further improvement of the instrument was effected by incorporating an automatic recording potentiometer in conjunction with the compensating optical system. This relieved the operator of the need to take galvanometer readings at fixed time intervals and overcame the objections of earlier instruments employing a photo-extinction turbidimetry principle.

The development of a potentiometer recorder capable

Fig. 1.—General view of the Bound Brook Photosedimentometer.

of detecting the small difference in output of the photocells in the Photosedimentometer, and having a speed of response sufficient to cope with the fastest falling particles of powder, was integral with the satisfactory operation of the Photosedimentometer. Messrs. Ether, Ltd. of Birmingham, agreed to undertake this work, and three years of close collaboration between the technical staffs of Ether, Ltd. and Bound Brook Bearings resulted in the development of a suitable potentiometer. This was based upon their " Wide Strip " recorder and, by virtue of many modifications, it was found possible to obtain a four-fold improvement on anything hitherto attained with a production model potentiometer recorder. The extremely high sensitivity coupled with the necessary speed of response is considered no mean achievement by the instrument industry and a step forward in potentiometer recorder design.

The interest shown by the powder metallurgy and allied industries prompted Bound Brook Bearings to place the instrument on the general market.

The Photosedimentometer has been designed with the object of putting sub-sieve analysis on a practical routine basis. It is primarily intended as a particle size comparator for the purpose of maintaining the consistency
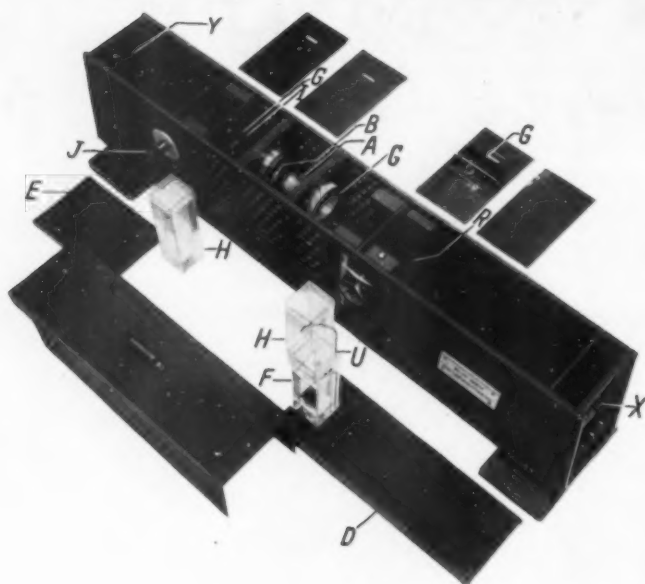
Fig. 2.—The construction of the optical unit.

Photosedimentometer can be used as a tintometer, as an absorptiometer for chemical analysis, or for measuring the opacity of filters, photographic negatives or coloured solutions, etc.

Description of the Instrument

The essential consideration in the design of this instrument is the production of two substantially parallel flat rectangular beams of light emanating from a common light source. A 30-watt filament bulb A and two pairs of plano-convex condenser lenses B and C are used to produce two parallel beams in opposite directions, and by interposing a series of slits, two flat horizontal beams of light pass through the working portions of the instrument on to a pair of matched photo-electric cells X and Y. As these two beams of light have a common origin, the ratio of their intensities is always independent of the brightness of the filament bulb.

The sedimentation tank F, in which the powder under test is allowed to settle out, is placed in the longer arm of the instrument. To minimise convection eddy-currents within the sedimentation medium, the infra-red component of the light is absorbed by suitable glass filters G and a dummy tank of clear liquid H. When the terminal velocity of the settling powder is low, any convection currents would become a source of considerable error. Provision is made for the sedimentation tank to be raised and lowered with respect to the beam of light in order to shorten the otherwise lengthy operating time when testing powders having a wide particle size range. By lowering the tank known distances, after the coarser fractions have settled out, the density gradient of the suspension can be obtained, and the quantity of extreme fines may thus be evaluated before sedimentation is complete.

During sedimentation, the instrument continuously records the average opacity of the illuminated volume within the sedimentation tank, and this opacity is defined as the ratio of the intensity of the light falling upon the illuminated volume to the intensity of the light leaving it. The intensity of the incident light is measured by the photo-electric cell Y in the shorter arm of the instrument, and similarly the intensity of the transmitted light by the photo-electric cell X in the longer arm containing the sedimentation tank. To take care of the small differences in the opacity of the glass tanks, etc., which are used, the instrument is arranged such that, when in correct adjustment, there is always a positive bias on the shorter arm. Before the powder is introduced, this bias is trimmed by means of a cut-off device J until equal illumination is obtained in both arms of the instrument. The electric current generated within the photo-electric cell Y, is fed through the 250-ohm slide wire M of the potentiometric recorder, and the current generated by the photo-electric cell X is fed through a matched 250-ohm resistor K. The volts dropped across

of powdered materials : for in the case of irregularly shaped particles it does not necessarily express the result in the same terms of particle diameter as any other method of size analysis. Each of these methods relies on assumptions regarding the particle shape and when the particles are not spherical, it all depends upon what you mean by " the diameter of an irregularly shaped particle ! " There are numerous corrections not affecting the reproducibility, which may be applied to the analysis so that a more exact result in terms of some classical definition of particle diameter is obtained : but, as the suitability of a specific grading will almost invariably have been agreed by other tests, these corrections have been found to be quite unnecessary in controlling powder quality from a given process of manufacture.

Only powders which can be made to settle out freely in some convenient liquid are suitable for analysis on the Bound Brook Photosedimentometer. This includes nearly all metal powders used industrially, most of the plastics and various silicious material from moulding sands to crushed and ground ores. With powders which are too fine to settle out within an hour or so, even in low viscosity liquids, the Bound Brook Photosedimentometer cannot be used to give a complete grading analysis : it will, however, give the specific surface for all powders which can be suspended in a chemically inert liquid. The specific surface, or average surface area per unit mass of powder, is perhaps the most significant single figure describing the fineness of a powder and, because it may be very rapidly determined on the Bound Brook Photosedimentometer, is often used as a quick check for suspect material before preparing a complete size distribution curve.

In common with other photo-extinction apparatus (which may not employ a suitable optical arrangement for powder fineness measurements), the Bound Brook

A Light source.
B & C Condenser lenses.
D & E Top covers.
 F Sedimentation tank.
 G Infra red absorption filters.
 H Dummy tank.
 I Optical density filters.
 J Cut-off device.
 R Adjustable platform.
 S Bulb holder.
 T Centreing bolts.
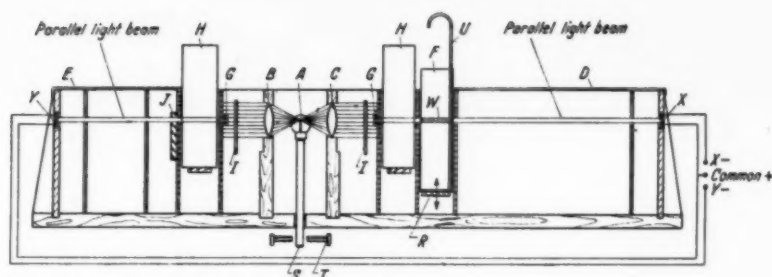 U Stirrer.
 W Illuminated volume.
X & Y Photocells.

Fig. 3.—Section through the optical unit.

this fixed resistor are automatically compared with the volts dropped across the slide wire, and when the potentiometer is in correct adjustment—i.e., no current passing through the null point galvanometer L, the ratio of the intensity of the light reaching the two photoelectric cells will be proportional to the distance of the slider along the slide wire. Hence, if the intensity as light source changes during sedimentation, it will affect both arms of the instrument equally and the ratio of the intensities will remain the same, and similarly the position of the slider for balance.

The instrument is of strong metal construction to prevent any distortion arising which may interfere with the alignment of the slits with respect to the photoelectric cells. Two terminals are provided at the back of the instrument for connection to the 6-volt supply from the power pack, and the three terminals at the end of the instrument are connected to the potentiometric recorder as indicated. The 250-ohm resistor is located within the potentiometer so that any temperature change will affect both the resistance of the bobbin and the slide wire simultaneously.

The trimming device J on the balance arm is fitted with a graduated dial to facilitate adjustment of the zero condition before commencing work. Two calibrated optical density filters I are provided and reference to these will show that the instrument is in proper adjustment. The power pack consists of a constant voltage transformer N which takes care of major voltage

fluctuations of the mains supply, a rheostat P which enables the bulb to be slightly under-run and thus lengthens its working life with minimum loss of efficiency, and a voltmeter Q which enables the operator to make this adjustment accurately. Provision is made to introduce two dummy tanks H one on each arm of the instrument, to act as heat absorbers or colour filters as required. The danger of convection currents within the sedimentation tank is greatly reduced by using a dummy tank filled with clear liquid immediately in front of the sedimentation tank. A similar dummy tank is then included in the balancer arm to maintain the similarity of the two arms.

The sedimentation tank stands on a platform R, the height of which may be smoothly adjusted within a range of about 12 cm. This is for alteration of the distance between the surface of the suspension and the light beam when required as sedimentation proceeds. A pointer moving over a centimetre scale on the front of the instrument accurately indicates the position of the platform with respect to the light beam.

There is a light-tight cover over each arm of the sedimentometer extending from the end to the third partition from the projector bulb in each case. There is also a loose metal dust cover which fits over the central part of the instrument and overlaps the other two covers. This loose cover is removed during determinations to permit convection cooling of the glass heat filters and the projector bulb.

Differentiation of Cobalt Oxides

By R. S. Young, Ph.D., F.R.I.C. and H. R. Simpson, B.Sc.

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A SIMPLE procedure for differentiating cobaltous oxide, CoO, from the higher oxides of cobalt, Co_2O_3 and Co_3O_4, brought to our notice by Murex Limited, of Rainham, England, deserves to be better known. It is based on the solubility of cobaltous oxide, and the insolubility of the higher oxides of cobalt, in dilute acetic acid under certain conditions.

Procedure— Place 1 g. of −100 mesh sample in a 250 ml. Erlenmeyer flask with 20 ml. water and shake well to ensure that all particles are thoroughly wetted. Add 30 ml. glacial acetic acid and attach to the flask a reflux condenser. Boil gently for one hour. Pour the contents of the flask on to a tared sintered glass crucible, or a Gooch crucible with asbestos, and wash thoroughly with hot water. Dry to constant weight in the oven

at 105° C. The residue represents $Co_2O_3 + Co_3O_4$, whereas the cobalt which is found in the acetic acid solution is derived from cobaltous oxide, CoO.

As in all determinations of this type, such variables as time of boiling, acidity, etc., must be carefully controlled. We have found, however, working with pure samples of cobalt oxides, that the solubility of the higher oxides and the insolubility of cobaltous oxide under these conditions is less than 0·5% and the reproducibility of results is quite satisfactory for industrial practice.

We have found that cobalt sulphide is virtually insoluble in dilute acetic acid under these conditions, and consequently cobaltous oxide can also be separated from cobalt sulphide by this procedure.

Flow-Through Electrode Tubes Suitable for Use in Routine Polarographic Analysis

By F. C. Spurr

T. J. Priestman, Ltd., Birmingham

TO facilitate the handling of large numbers of samples at the final stage on the polarograph, some easy means of changing the solutions to be analysed is very desirable. The electrode systems developed to date—excellent as they may be for research—are unsuitable for routine work in a busy laboratory.

The introduction of the silver-chloride-coated silver wire as anode, by Lingane,[1] was a big help, and the practice of clamping the solution-containing test tube in position round the electrodes resulted. Between samples, however, it was necessary to wash and attempt to dry the wire and capillary round which it was coiled—a troublesome procedure, to say the least. The drops from the capillary and washing water had to be dealt with and drying the wire tended to distort it.

To overcome these difficulties, the simple form of flow-through tube shown was introduced, connected to a water-actuated filter-pump via a large separating funnel, the latter providing a trap for mercury, which is readily recovered. Washing the electrodes is now easily accomplished by using part of the solution under test before filling the tube to just above the wire coil.

The next step was to attempt to eliminate the wire and use a mercury pool anode. To this end, the second tube illustrated in Fig. 1 was devised and has given

1 J. J. Lingane, *Ind. and Eng. Chem., Anal. Ed.*, 1944, **16**, 329.
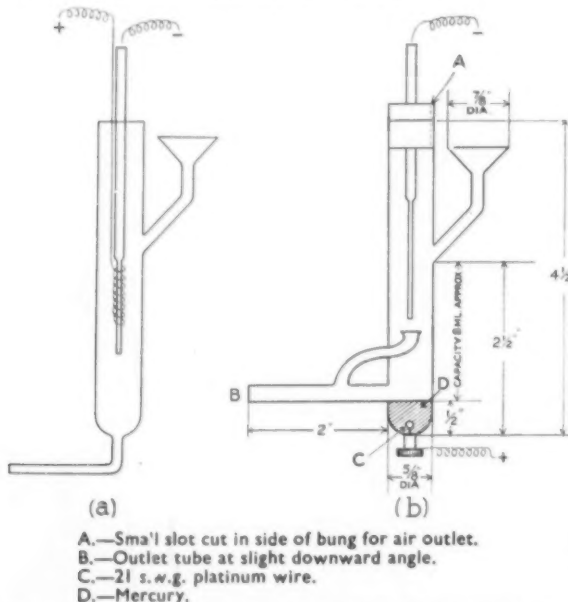
Fig. 1.—Flow-through tubes for use with the polarograph :
(a) with silver wire ; (b) with mercury pool.

A.—Small slot cut in side of bung for air outlet.
B.—Outlet tube at slight downward angle.
C.—21 s.w.g. platinum wire.
D.—Mercury.
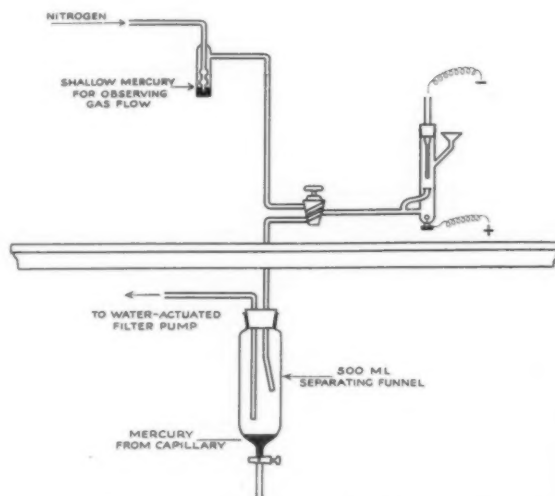
Fig. 2.—Bench connections for flow-through tube using 3-way tap with nitrogen on one side (for " blanketing " if found necessary) and suction on the other. A separating funnel is located under the bench for mercury recovery.

excellent results. It will be noted that the mercury from the capillary does not drop into the pool.

Because it sometimes happens that mercury will not drop from the capillary due to an air lock or other cause, two tubes have been set up, side by side, and by introducing another three-way tap, T-pieces and a good double-pole change-over switch, the same pump can be used with either tube and an immediate change can be made when the need arises, thus avoiding a hold-up and much annoyance.

It will be seen that provision is made (via the three-way tap) for a nitrogen " blanket " in the tube ; this meets objections to pouring the de-oxygenated solutions through the air in the flow-through tube. The important adjustment of the temperature of the solutions to be polarographed is arranged by allowing the de-oxygenated solutions (including the standards put on with every group) to stand in the polarograph room long enough to reach a steady state. The lunch-hour break is usually sufficient for this purpose.

It may be of interest to mention that the method devised by Stross[2] for the determination of zinc in aluminium alloys is being used quite satisfactorily, without centrifuge, and with certain modifications of apparatus and manipulation. Easily reproducible results are obtained quickly and the graphs are good.

Since the solutions used for zinc determinations are strongly alkaline, the apparatus needs to be washed with

2 W. Stross, *Metallurgia*, 1947, **36**, 163-166, 223-225.

plenty of water at the conclusion of operations.

All glass taps are lubricated with "silicone grease," which has been found most satisfactory. No difficulty has been experienced from possible corrosion of the metal "filter-pump" during a period of over eighteen months.

These tubes, which are robust and inexpensive, have been in use in the laboratory of T. J. Priestman, Ltd., Birmingham, for well over a year, and the author wishes to thank Mr. R. T. Priestman, Governing Director, for permission to publish these particulars.

Investigations on Colorimetric Methods of Metallurgical Analysis

Part IV.—Estimation of Silicon in Steel Using the Duboscq Type of Colorimeter

By G. V. L. N. Murty, M.Sc., A.R.I.C., D.Sc., F.A.Sc. and N. C. Sen, B.Sc.

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IT has been shown by one of the authors[1] that if suitable light filters are used in conjunction with the usual Duboscq-type colorimeter, colour matching is made considerably easier, leading to a remarkable increase in the accuracy of the results obtained. The governing consideration in the choice of filter is that it should be, as nearly as possible, complementary in colour to the solutions to be examined. The investigations have been extended to the estimation of silicon in steel by the molybdenum blue method,[2] suitably modified in the light of experience. The filter (Ilford Spectrum Red Filter 608) is held on the top of the eyepiece and the whole field viewed through it. In this way, it has been possible to obtain with remarkable ease reproducible results, comparable in accuracy with those obtained by the use of the Spekker Photo-electric Absorptiometer. In the present paper, the detailed procedure is followed by a comparative statement of the results obtained by the colorimetric, absorptiometric and gravimetric methods of analysis in a few typical cases.

The steels investigated fall into three categories, corresponding to low (up to 0·10%), medium (0·10–0·60%), and high (above 0·60%) silicon contents. In the earlier stages, attention was mainly confined to plain carbon steels, as it had been found that for those rich in alloying elements, the blank is somewhat yellow and the final solution often greenish rather than blue. Subsequent findings have indicated, however, that the visual colorimetric procedure may also be followed in the case of alloy steels, provided that sufficient care is taken in the choice of standard. It should contain similar amounts of alloying elements to the "unknown" samples and, hence, the same standard cannot be used in all cases.

Procedure

For dissolving steel drillings, an oxidising mixture,[3] consisting of ammonium persulphate dissolved in dilute

TABLE I.—PLAIN CARBON STEELS

Si %			C %	Mn %	S %	P %
Visual	Absorptio-metric	Gravi-metric				
0·050	0·053	0·058	0·12	0·39	0·042	0·062
0·074	0·077	0·064	0·08	0·32	0·041	0·043
0·090	0·091	0·088	0·11	0·37	0·046	0·061
0·100	0·098	0·121	0·60	0·47	0·046	0·035
0·155	0·145	0·175	0·34	0·70	0·038	0·040
0·220	0·210	0·200	0·46	0·70	0·036	0·048
0·280	0·300	0·275	0·34	0·65	0·032	0·039
0·328	0·343	0·324	0·57	0·68	0·044	0·020
0·400	0·387	0·376	0·42	0·75	0·034	0·032
1·36	1·44	1·50	0·48	0·90	0·025	0·041
1·92	1·86	2·00	0·52	0·99	0·018	0·039

TABLE II.—ALLOY STEELS

Si %			C %	Mn %	S %	P %	Co %	Mo %	W %	V %
Visual	Absorptio-metric	Gravi-metric								
0·140	0·127	0·130	0·27	0·16	0·010	0·020	3·90		9·04	0·18
0·150	0·150	0·132	0·25	0·18	0·017	0·022	3·48		9·14	0·26
0·160	0·157	0·179	0·27	0·21	0·015	0·022	3·45		9·21	0·11
0·240	0·225	0·246	0·89	0·23	0·014	0·036	1·40	0·38		
0·260	0·270	0·282	0·70	0·21	0·011	0·012	4·20		18·63	1·18
0·290	0·310	0·329	0·70	0·26	0·010	0·013	4·06		17·92	1·20
0·330	0·352	0·357	0·77	1·62	0·027	0·037		0·16		0·14
0·330	0·360	0·329	1·88	0·42	0·014	0·028	10·40	0·27		
1·40	1·39	1·40	0·35	0·21	0·010	0·022	1·25		2·00	
1·46	1·40	1·42	0·36	0·18	0·011	0·021	1·20		1·92	

sulphuric acid, is used instead of 5% sulphuric acid as recommended by Vaughan (*loc. cit.*). This results in a saving of ten minutes in the time taken to dissolve the sample, which is indeed appreciable in a method whose total time ranges from forty to fifty minutes. A further reduction of ten minutes is effected by allowing only five minutes after the addition of stannous chloride, instead of fifteen minutes, which has been found to be unnecessary in tropical conditions.[4]
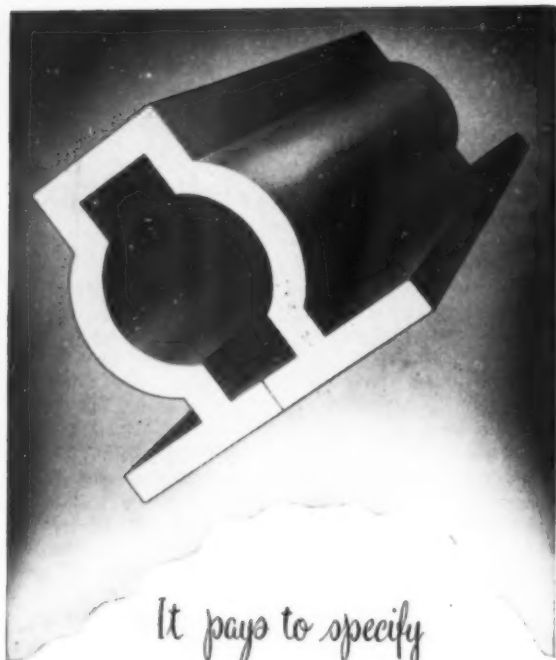
A steel which has been accurately analysed a number of times by the usual gravimetric procedure, and whose silicon content is in the middle of the range under investigation, is used as a standard for the visual comparison of the colour intensities. In this connection it has been found convenient to adopt a 0·05% silicon

1 Murty, *Proc. Ind. Sc. Cong.*, 1945.
2 Vaughan, The Institute of Chemistry Lecture on "Further Advances in the Use of the Spekker Photo-electric Absorptiometer in Metallurgical Analysis." 1942, pp. 6–8.
3 Murty and Sen, *Curr. Sci.*, 1948, **17**, 363.

4 Murty, *Proc. Ind. Sc. Cong.*, 1945.

steel for the low range, and 0·30% silicon steel for the medium range. For the high range, however, it is desirable to take aliquot portions of the solutions. It is often found that, with the same solution in the two cups of the colorimeter, the readings corresponding to the plunger heights at the position of colour matching are not identical. It is, therefore, essential in most cases to compensate for the zero error. A modification has been introduced in the operating details for comparing the colour intensities. By this, the need for effecting calculations based on inverse proportionality of percentage concentration and the corresponding scale readings has been obviated, and the zero error correction is automatically adjusted, thereby making it possible to read the silicon percentage directly. The procedure is outlined below.

The blue solution corresponding to the standard steel, e.g., 0·30% silicon, is taken in both cups and the right hand one fixed at the reading 30. The left hand side is now adjusted to a satisfactory matching of colour and the reading noted, say 32. The unknown solution is then taken in the left hand cup and its position fixed at 32. The cup containing the standard solution on the right hand side is then adjusted to a satisfactory condition of colour matching. The reading on the right hand scale (e.g. 40) gives immediately the percentage of silicon in the sample as 0·040.

Results

A large number of steels, covering a wide range of composition, have been analysed for silicon by visual (colorimetric), absorptiometric and gravimetric methods and the results obtained in a few typical cases are set out in Tables I and II.

These results indicate clearly that the visual procedure now recommended for the estimation of silicon in steel is quite comparable, with regard to the accuracy attainable with the absorptiometric and gravimetric methods of analysis.

Acknowledgments

The authors' thanks are due to the management of the Tata Iron & Steel Co., Ltd., for permitting the publication of this paper, and to Dr. J. C. Ghosh and Mr. N. B. Sen, the present and former Chief Chemists, for their keen interest in the work.

Fatigue Bibliography for 1950

THERE has been issued by the American Society for Testing Materials a list of references to articles published in 1950 dealing with Fatigue. This was prepared by Committee E-9 on Fatigue (a group of leading experts on fatigue testing and the significance of fatigue properties) through the work of a Survey Sub-committee headed by Professor T. J. Dolan, University of Illinois, Urbana.

Brief abstracts of the articles have been included when these were readily available. The list is not exhaustive but may be sufficiently extensive to be of interest to those concerned with this field. Both the nature and format of this list is experimental. References are generally so arranged that sheets can be readily cut apart for filing according to any desired plan. If there is sufficient interest in lists such as this, it may be possible to provide other additional lists periodically—for example, every six months. Copies of the list of Articles on Fatigue, comprising 28 duplicated pages, 8½ by 11 in., can be procured from A.S.T.M. Headquarters, 1,916, Race Street, Philadelphia 3, Pa., at $1.50 each.

HALE AND HALE (TIPTON) LTD.

Reputation of Products Further Enhanced

.

Mr. W. Edgar Hale's Review

The 15th Annual General Meeting of Hale and Hale (Tipton), Ltd., was held on December 19th, at Dudley, Mr. R. C. Leppington (Vice-Chairman and Managing Director) presided, in the absence of the Chairman, Mr. W. Edgar Hale, M.I.Mech.E., M.Inst.F.

The following is an extract from the Chairman's circulated review :—

Our trading during the year has been quite a successful one, and we have enhanced still further the already excellent reputation that our company has for its products.

Parent Company—The profit and loss account shows a trading profit of £89,963, as compared with £73,162 and there remains a balance of £36,147 representing the net profit for the year, an increase of £6,399. Your directors recommend a final dividend of 17½ per cent., less tax, making a total distribution for the year of 25 per cent., less tax, as compared with 20 per cent. for the previous year. This final dividend takes £9,188 and it is proposed that an amount of £20,000 be transferred to general reserve account to leave a balance to be carried forward of £12,958.

The consolidated trading profit for the year amounts to £120,077, as compared with £78,362 ; the consolidated net profit is £50,241, an increase of £13,506. After giving effect to the dividends already paid and the appropriations as recommended, there remains a balance of £16,878 to be carried forward as compared with £27,204 brought forward.

PRODUCTION, SALES AND MANAGEMENT

On our sales side, we are continuing to divide up our production by the exercise of the best method possible. Our Blackheart malleable iron castings, and also our new product which we are selling under the name of "Permalite," are exceedingly popular, and I do not think I am exaggerating the position when I state that there is nothing quite so good on the market.

Our products are supplied to almost every branch of the engineering industry, and it would be difficult to visualise any commercial organisation having a more secure foundation upon which to build its

goodwill ; thus one can be fairly certain that when one branch of engineering is having a lean time, some other section will be having the opposite.

With the rearmament programme, which is engaging our attention, the question of supply and demand is going to present an obstacle, but we are using our best endeavours to increase production, and for this purpose we visualise quite a considerable capital expenditure during the current trading year.

We have introduced during the year a very interesting appliance for materially improving upon the present method employed in the launching of ships. The first launch took place recently of an ocean-going oil tanker, and the result was excellent.

We are a well-balanced team, both in respect of management and production. The success of this enterprise is due to the energy and determination of everyone associated with it that makes it the powerful force it is in the industry to which it belongs.

CURRENT OUTLOOK

Our financial position as a company is excellent, and is the outcome of taking much care of our finances for many years. One can only describe them as definitely satisfactory.

At this point one has to devote some attention to the question of "profit." The only real profit that the proprietors of any business secure is such an amount that is divided annually between them. The whole of the remainder is absorbed in the enterprise, to replace worn-out plant and buildings, and other contingencies which arise in the course of business. There are some people in the highest political spheres who are prepared to suggest that there is something definitely immoral about the making of profit. It is only out of profit that either our company or any other concern can build up a sound financial organisation. Taking our own position, for every £'s worth of value which we supply to our customers, 18s. 0½d. is absorbed in materials, wages, repairs and

overheads, taxation takes 1s. 2½d. and only 9d. remains as profit. It may be interesting to note that the amount paid in wages and salaries is approximately ten times this figure of profit.

One cannot divorce the question of taxation from commercial finance, but the amount which is paid in taxation by industry to-day is just colossal and is, of course, a continual drain upon liquid funds ; but there is nothing that can be done about it.

RAW MATERIAL SHORTAGES

It is well known that world supplies of metallic ores, fuels and all other basic materials are already in very short supply, due, in the main, to the over consumption of these supplies in the attempt to improve the standards of living everywhere. The present supplies are really insufficient to keep a first-class peace programme working to the full, so that the extra demand necessary for arms production is going to be exceedingly difficult to fulfil. It becomes self-evident that, as a nation, we are going to be deprived of some of the important necessities of life, and the consuming public have just got to suffer and put up with it.
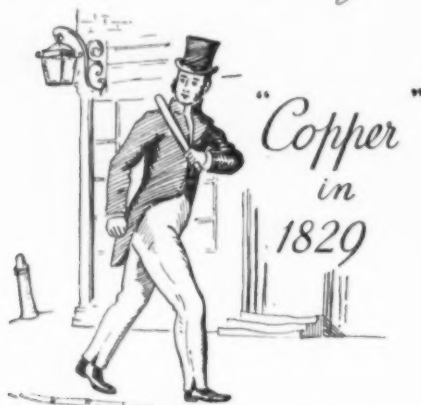
Then there is the all important question of fuel. We have, of course, suffered fairly considerable inconvenience at times in regard to supplies of solid fuel, gas and electricity, and there is no gainsaying the fact that our national position in respect of these vital supplies is worsening, and here again, the solution is most difficult. The using of less fuel in producing finished articles has made some slight alleviation, and this process will be continuous : but it is all so slow. Nevertheless, it is at least a crumb of comfort.

In mentioning the very important adverse problems with which we are faced nationally, the inclination is to be pessimistic, but if we meet our troubles in the same bold spirit we have adopted in the past, I am sure we shall eventually reach a brighter period.

The report was adopted.